PROPRIETARY

(Presentation)

NAVY'S ALL-ELECTRIC SHIP PROGRAM

Technology : Intelligent Standardized Actuators

Category : Ship Auxiliaries
Propeller, Water Vanes, Valves, Pumps, Elevators

Principal Investigator:

Prof. D. Tesar, Carol Cockrell Curran Chair in Engineering
Director, Robotics Research Group

In Concert With:

Dr. R. Hebner, Director, Center for Electromechanics
Mr. W. Shutt, Prog. Manager, Applied Research Lab.
Prof. K. Ramu, Electrical Engineering,
Virginia Polytechnic Institute

Topics:

Science Base for Intelligent Actuators
Standardized Actuator Building Blocks
Submarine Water Vane Actuators
Compact Propeller Drives
Shipboard Weapon's Handling
Open Architecture Ship

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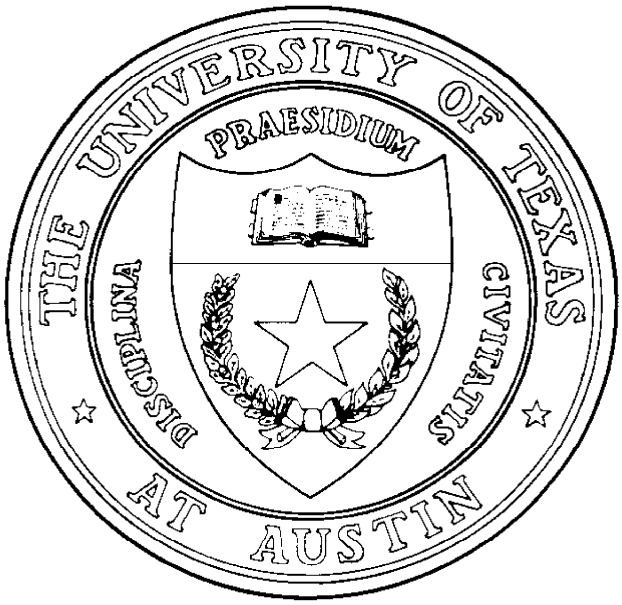
July 5, 2002

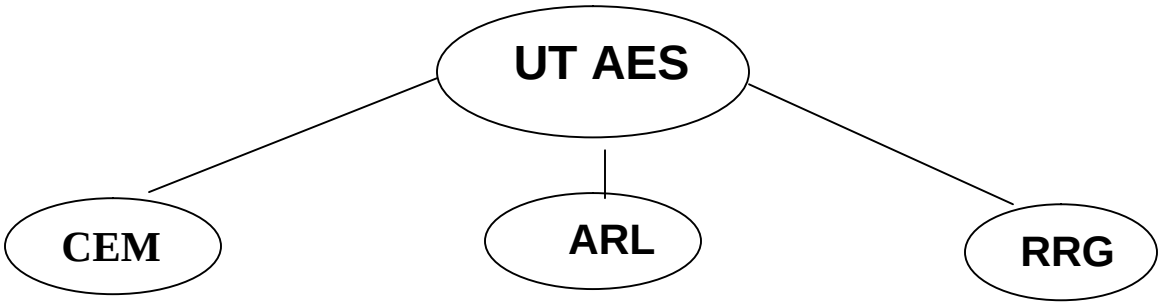


TECHNICAL THRUST

TO PRODUCE MODULAR SYSTEMS WHICH EXHIBIT ADVANCED PERFORMANCE AT REDUCED COSTS WHOSE ARCHITECTURE MATCHES THAT OF TODAY'S COMPUTERS, ALLOWING RAPID REPAIRS AND A REDUCED THREAT OF OBSOLESCENCE.

The University of Texas at Austin
Robotics Research Group
January 1998

The University of Texas
All-Electric Ship Program



Prime Movers

Advanced Materials

Large Actuator Prototypes

Motor/Pumps

Motors/Generators

Flywheel Batteries

Pulsed Power

Aircraft Elevator

Army Applications Requirements

Miniaturized Sensors

Signal Analysis

Real Time Software (Embedded)

CBM (Fault Detection and Identification**)**

Systems Integration

Information Management

Training Regimes

Navy Applications Requirements

Actuator Architecture (Design, Intelligence)

Interface Standards

Actuator Software (Performance Criteria, CBM)

Actuator Testing (Four Test-Beds)

Weapons Elevators

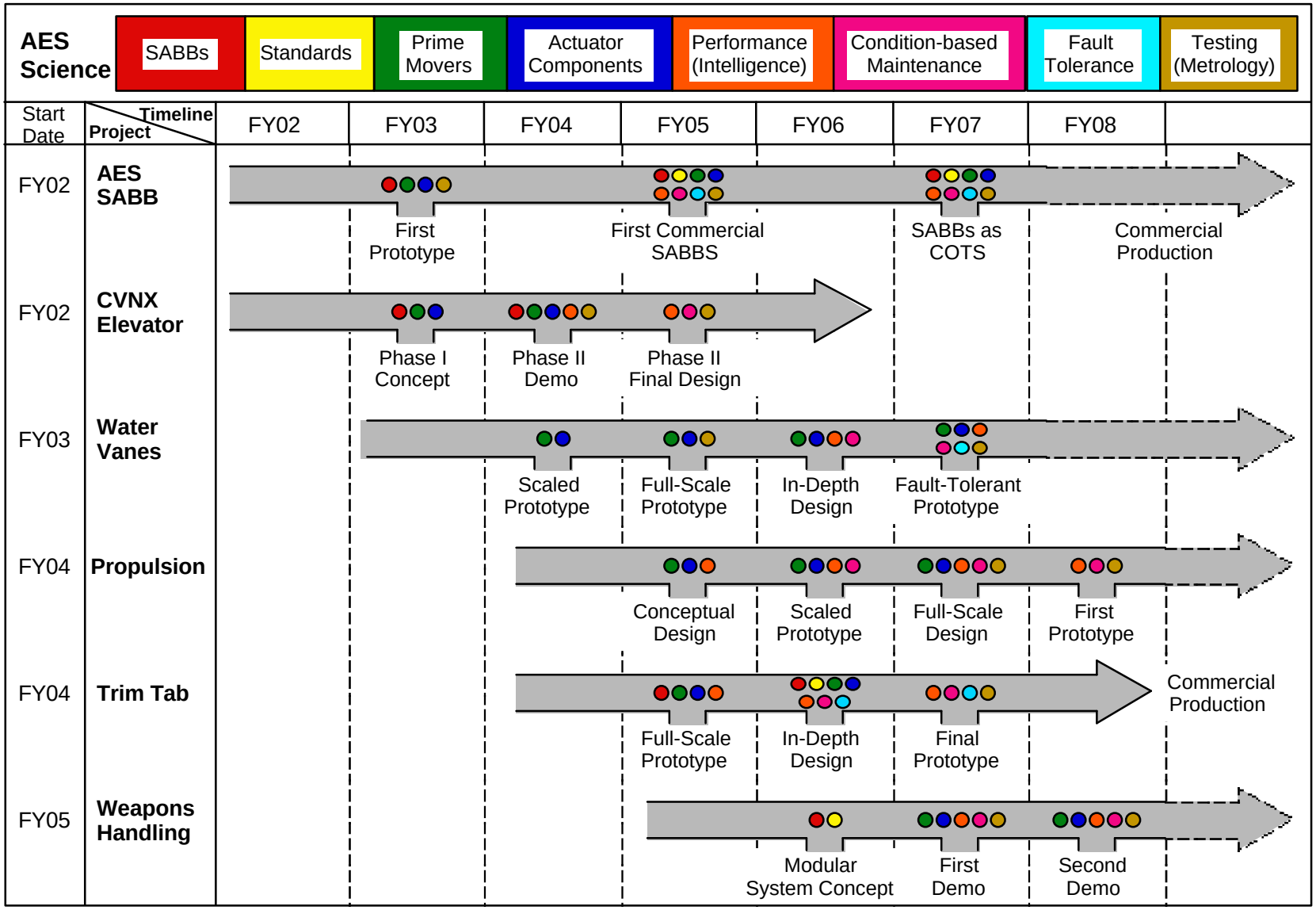
Weapon's Handling

Water Vane and Propulsion Modules

Aerospace Applications Requirements

CEM – Center for Electro-Mechanics
ARL – Applied Research Laboratories
RRG – Robotics Research Group

Overall AES Actuator Project Development Plan



Colored circles (●●●●) in project timeline arrows show relevant AES Science topics for each development phase.

OVERVIEW Of ACTUATOR PROGRAM

1. **Drives Anything That Moves on Ship**
   - **Replaces All Hydraulics**
   - **Standardization Enhances Simplicity**
     - Opens Up Ship Architecture
     - Dual of the PEBB
   - **Dramatically Improves Maintainability**
   - **Exceptional Ruggedness/Survivability**
   - **Potentially Reduces Weight/Volume by 5X**
2. **Further Develop Every Required Technology**
   - **Exceptional Gear Train**
     - 5X Increase In Torque Capacity
     - 15X Increase In Stiffne**ss**
   - **Advanced Prime Mover**
     - Switched Reluctance Motor
     - Modern Electronic Controller
   - **Compact Actuator Design**
     - Only 5 Principal Parts
     - Temperature/Tolerance Insensitive
   - **Intelligence For Enhanced Performance**
     - Eight Orders of Magnitude Improvement Over Two Decades (1990 – 2010)
     - CBM/Fault Tolerance
3. **Eight Distinct Ship Applications**
   - **Submarine Water Vanes**
   - **Propeller Pod Drive Modules**
   - **Weapon's Handling System, ETC.**
4. **Industrial/Commercial Participation**
   - **10 Interested Corporations**
     - Rockwell, Timken, Curtiss-Wright, Boeing, Newport News, etc.

Open Architecture Objectives

1. BENEFITS

- **Reduced Total Ownership Costs**
- **Reduced Manning**
- **Enhanced Survivability**
- **Increased Fighting Capacity**
- **Reduced Logistics Trail**
- **More Rapid Upgrades**
- **Reduced Threat of Obsolescence**

2. PRINCIPAL ACTUATORS

- **Replace All Hydraulics**
- **Water Vane Operation**
  - Rotary
  - Linear
- **Propulsion Module**
  - Motor/Gear Combination
  - External Pod Configuration

3. AUTOMATION OPPORTUNITIES

- **Launch Systems**
- **Control Surfaces**
- **Firemain Reconfiguration**
- **Valves, Doors, Hatches, Etc.**

4. ROBOTIC APPLICATIONS

- **Weapons Handling/Aircraft Preparation**
- **Stores Handling and Warehousing**
- **Hull Inspection and Maintenance**
- **Aircraft Refueling/Firefighting**
- **Scullery/Bilge Cleaning**

Future Ship Needs Provided By SABB's

(Navy Requirements)

1. COMBAT EFFECTIVENESS

Sustainability	**Resupply SABB's From Minimal Set of Spares**
Maneuverability	**Reduced Weight and Volume, More Accurate Control of Submarine Water Vanes**
Ordnance Load-Out	**Automate Weapon's Handling And Make-up**
Sortie Response	**Aircraft Carrier Weapon's Elevator Utilization Up By 5 X**

2. INCREASE SURVIVABILITY

Damage Tolerance	**Design For High Level Of Ruggedness And Shock Resistance, Fault Tolerance**
Damage Control	**All Ancillary Components Associated With Hydraulics Removed From Ship**
In-Situ Replacement	**Plug-and-Play Replacement From Spares Immediately After Hit**
Signatures	**Concentrate All Sciences To Reduce Signatures From Minimal Set of SABB's for All Navy Applications**

Figure IV.1.1

Future Ship Needs Provided By SABB's
(Navy Benefits)

3. REDUCE TOTAL OWNERSHIP COST
(Acquisition)

RDT&E	**Concentrate Development On Minimal Set Of SABB's**
Production Cost	**Standardize SABB Production, Leverage Industrial COTS**
Design Costs	**In-Depth Design Of Minimal Set Of SABB's**
Acceptance Costs	**In-Depth Certification Of Minimal Set Of SABB's**

4. REDUCE TOTAL OWNERSHIP COST
(Operations And Support)

Manning & Training	**Finite Number Of Standardized SABB's**
Repair & Maintenance	**Plug-and-Play, Quick Change Out At Sea**
Upgrades & Modernization	**Immediate Tech Mods At Sea By Nominally Trained Technicians**
Operational Status	**Conditioned-Based Maintenance For Continuous Awareness of Performance Reserve**

Figure IV.1.2

SHIP ACTUATOR TECHNOLOGY BASELINE

I. PRESENT BASELINE

- **Most Actuators Are Hydraulic**
  - Connections, Piping, Fluids
  - Pumps, Valving, Reservoirs
  - Circulation Systems
  - High Maintenance History
- **Virtually No Situational Awareness**
  - Independent Operation(s)
  - Manual Controls
  - Minimal Sensors
  - Nominal Performance

II. ONR EMPHASIS

- **Fight Through** (Survivability)
- **Reconfigurability** (Fault Tolerance)
- **Reduced Weight** (Volume)
- **High Efficiency** (Reduced Thermal Loads)
- **Reduced Manpower** (Simplified Training)
- **Reduced Emissions** (All Types)

III. EXAMPLE FUTURE BASELINE

- **Stern Planes** (Present)
  - Linkages, Bearings, Hydraulics, Pistons, Hull Penetrations
- **Water Vanes** (Future)
  - Reduce Weight/Volume
  - Take Actuation Outside Hull
  - Improve Shock Resistance
  - Improve Quietness
  - Distributed Small Water Vanes
  - Trim Tabs
- **Propulsion** (Future)
  - External Pods/Quick Change?
  - Directed Force Vector/Steering?
  - Gimbaled Pod?
  - Universal Joint Pod Support?

Overall Contribution of University of Texas Robotics Research Group

1. **ACTUATOR SCIENCE BASE** (SABB'S)
   - **Standardized Interface / Optimum Design**
   - **Maximum Performance Envelope**
   - **10 Sensor Environment**
   - **Condition-Based Maintenance**
   - **Fault Tolerance**
2. **AUTOMATION/WEAPONS HANDLING**
   - **Build Systems On Demand**
   - **Minimal Set** (13) **of SABB's**
   - **Reduce Manpower by 300%**
   - **$250 Million Cost Savings Per Aircraft Carrier**
3. **MODERN WEAPONS ELEVATOR CONCEPT**
   - **Improves Utilization by 500%**
   - **Climbing Gear/Rack Actuators**
   - **Condition-Based Maintenance For All Actuators**
   - **Open Architecture Carriage Platform**
   - **No Cables, No Umbilical, No Machinery Room**
   - **New Ballistics Hatch**
4. **MOBILE PLATFORM FOR WEAPONS TRANSPORT**
   - **Modular/Standardized Wheel Module**
   - **12" Total Height**
   - **Automated Shipboard Navigation**
   - **Rugged/High Survivability**
   - **Replaces Lift Trucks and Push Carts**

Overall Contribution (cont.)

5. ALL-ELECTRIC SUBMARINE WATER PLANE ACTUATORS

- **Remove All Hydraulics**
- **Torque Capacity Up To 750,000 ft.-lb.**
- **Fault Tolerance/High Survivability**
- **Rugged / Shock Resistant Designs**
- **Reduced Volume/Weight/Complexity**

6. FAULT TOLERANT WATER VANE DRIVES

- **For Future Submarine Applications**
- **90,000 ft.-lb. Torque**
- **14” Wide / 32” In Diameter**
- **Dual Pancake Switched Reluctance Motors**
- **Rugged / Quiet Gear Train**

7. TRIM TAB WATER VANE ACTUATOR

- **For Precision Submarine Maneuvers**
- **Trim Tab on Edge of Water Vane**
- **6x Redundancy / Fault Tolerance**
- **Exceptional Torque-To-Weight Ratio**
- **Exceptional Stiffness / Ruggedness**

8. EXTERNAL ELECTRIC SHIP PROPELLER POD DRIVE

- **3,000,000 ft.-lb. Torque at 40 RPM**
- **20,000 HP / 20,000 RPM Motor**
- **Extremely Compact / Rugged 500-to-1 Gear Train**
- **Self-Contained Replaceable Module** (at Sea)
- **Enhances Ship Availability**

9. ELECTRICAL-MECHANICAL CATAPULT

- **Dual High Speed Flywheels** (10,000 RPM)
- **Dual Clutches Drive Dual Gear Trains**
- **Differential Drives Cable Drum**
- **Controlled Acceleration of Aircraft**
- **Exceptional Compactness / Weight**
- **Reduced Volume/Weight/Complexity**

UT AUSTIN LISTING OF MAJOR REPORTS

(126 Since 1985)

	TOPIC	NO. OF REPORTS
1.	Assessment of Application Requirements	6
2.	Kinematic Design of Manipulator Systems	5
3.	Dynamic Modeling Of Manipulator Systems	10
4.	Metrology and Measurement Of Manipulator Systems	4
5.	Control of Manipulator Systems	15
6.	Operational Software for Manipulator Systems	23
7.	Actuator Development	34
8.	Structural Design Of Manipulator Systems	14
9.	Electronic Controller Development	11
10.	Integrated Manufacturing Cells	4

ACTUATOR TASK DISTRIBUTION

	AES (Science)	URPR (Rugged)	Boeing (Fault Tolerance)	VASCIC (Standard)	PANTEX (Light Duty)
Gearing	**Park** (60%)	**Park** (20%)		**Park** (20%)	
SRM (Others)	**Ashok** (40%)		**Ashok** (20%)	**Ashok** (20%)	
Criteria	**Ashok** (20%)				
	Yoo (40%)				
	Song (30%)				
	Linsey (50%)				
Design	**Shin** (20%)	**Shin** (20%)		**Janardhan** (60%)	**X1** (30%)
	Gloria (40%)		**Gloria** (60%)	**Banks** (20%)	
Sensors	**X1** (40%)	**Hvass** (10%)	**Hvass** (10%)	**Hvass** (10%)	
Operations SFW	**Song** (20%)		**Song** (30%)		
CBM	**Hvass** (70%)				
	Song (20%)				
Fault Tolerance	**Boztas** (30%)		**Boztas** (30%)		
Components	**Janardhan** (40%)		**Boztas** (20%)		**Boztas** (20%)
	Kang (20%)		**Kang** (20%)	**Kang** (20%)	
Interfaces	**Shin** (40%)	**Shin** (20%)		**Banks** (20%)	
Testing	**Kang** (40%)	**Yoo** (50%)	**Yoo** (10%)		
Navy Integration	**Banks** (60%)				
Prototypes	**Vaculik** (20%)	**Vaculik** (80%)		**X1** (30%)	**Linsey** (50%)
	7.00	**2.00**	**2.00**	**2.00**	**1.0** **(14 Total)**

Note: In January 2003, we may add **X3** in Components and Light Duty Actuators and move Boztas to Design work under Boeing.

Potential Industrial Partners For Intelligent Actuator Development

	PARTNER	APPLICATIONS
1.	**Newport News Shipbuilding**	Submarine Water Vane Actuators Aircraft Carrier Weapon's Handling Improved Elevator Technology
2.	**AMSEC**	Improved Ship Maintenance and Spares Logistics
3.	**Rosenblatt**	Open Architecture Ship Standardized Actuators For the Navy
4.	**Unidynamics**	Ship Support Systems (Doors, Hatches, Elevators, Etc.)
5.	**Rockwell**	Ship Electric Drives Advanced Prime Movers
6.	**Timken**	Standardized Actuators Special Bearings and Gear Trains Distributed Sensor Arrays
7.	**Boeing**	Fault Tolerant Aircraft Actuators
8.	**Curtiss-Wright**	Actuators For Aerospace Industry
9.	**Bechtel**	All-Electric Construction Equipment
10.	**General Motors**	Open Architecture Mfg. Cells Electric Wheel Drives

RESEARCH PROGRAM AT UT AUSTIN

1.	**NAVY** (June 2002) (Fall 2004)	- **All-Electric Ship Initiative** RRG on Actuator Science Actuator Development	$280K/1st Yr. $2.0 mil/Yr.
2.	**Aircraft Carrier** (Fall 2002)	- **Consortium of Universities To Provide Weapons and Stores Handling** (Navy, NNS) (Virginia, VA Tech, Old Dominion)	$100K/1st Yr. $1.45 mil ($4 mil)
3.	**DOE** (Continuing)	- **Dismantle Nuclear Facilities Nuclear Weapons Disposal Rugged Actuator Development**	$865 K/yr.
4.	**TEXAS ATP** (Fall 2001)	- **Machine Performance Criteria Development, Testing and Demonstration**	$250 K (2 yrs.)
5.	**FAA** (Sum. 2003)	- **Commercial Aircraft Safety** (Consortium of UTexas, UTenn, FA&M, VPI)	$1.0 mil/yr. ($2.5 mil/yr.)
6.	**Aircraft Actuators** (Spring 2002)	- **Boeing Organized Fault Tolerant Actuator Prototype** (With VPI, Approach Air Force)	$100K ($500K)
7.	**DOE** (Fall 2002)	- **Nuclear Weapons Dismantle-ment Operations** (Pantex)	$200K/yr.
8.	**International University**	- **Open Architecture Manufacturing Cells** (UT Austin, Prague, Singapore, et al)	(?)

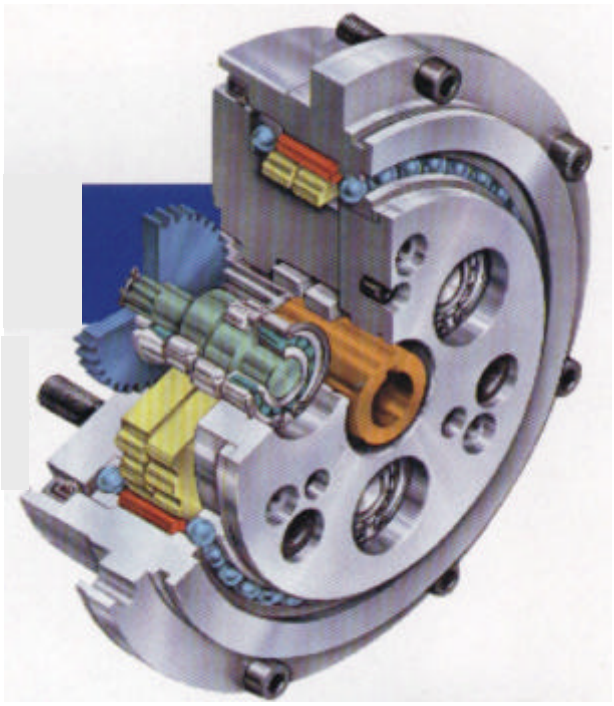
ACTUATOR SCIENCE BASE DEVELOPMENT

1. **Standardized Actuators**
   - Drives Everything That Moves
   - Emphasis On Ruggedness/Simplicity
   - Reduces Weight/Volume By 5X
2. **Open-Architecture Interfaces**
   - Plug-and-Play By Nominal Technician
   - Minimal Set of Actuators (13)
3. **High Performance Based On Intelligence**
   - Expanded Performance Envelope (3X)
   - Embed 10 Sensors In All Actuators
4. **Exceptional Component Technologies**
   - Gear Trains, Motors, Controllers, Sensors
   - Integrated In Full Actuator Architecture
5. **Condition Based Maintenance**
   - Model Based/Finite Fault Tree
   - No False Alarms
6. **Operational Criteria**
   - Criteria Balanced For Best Performance
   - Actuator Operating Software
7. **Fault Tolerance/Reconfiguration**
   - Survival Under A Fault/Failure
   - Force and Velocity Summing Configurations
8. **Test Regime**
   - Four Distinct Test-Beds
   - Document Performance “As Built”
9. **Interface To Ship Control System**
   - Dual of PEBB Concept
   - Situational Awareness To Control Centers
10. **Actuator Prototype Development**
    - In Concert With Industry
    - Meet Customer Requirements
    - Certification By Carderrock/Philadelphia

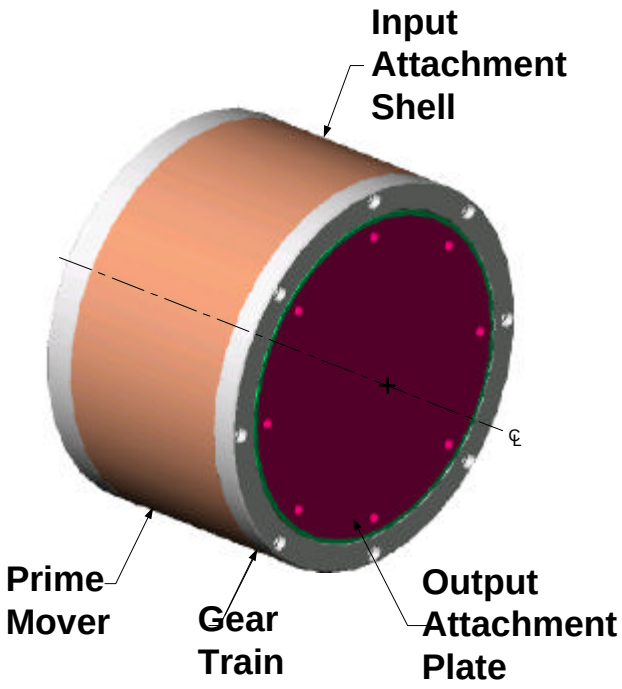
SHIP APPLICATIONS UNDER DEVELOPMENT

1. **Ruggedized Standard Actuator Module**
   - Replaces All Hydraulics
   - Compact, Stiff, Shock Resistant
   - Exceptional Performance/Intelligence
   - Maintenance By Unskilled Technician
2. **Water Vane Trim Tab**
   - Provides Precision Maneuver Control
   - Fault Tolerant Rotary Module (6” x 15”)
   - 3 Modules Produce 25,000 ft-lb. Torque
3. **Open Architecture Weapons Elevator**
   - Elevator Utilization Up By 5 X
   - Removes All Machinery Room Space
   - Doubles Load Capacity
4. **Mobile Weapon’s Transport Platform**
   - Modular/Low Profile of 12”
   - Intelligent/Autonomous Navigation
5. **Open Architecture Weapon’s Handling System**
   - Robots, Warehousing, Weapon’s Assembly, etc.
   - Made Up of 13 Standardized Actuators
   - Reduces Manpower By 4X
   - Saves $350,000,000 over 50Year Life Of Carrier
6. **Fault Tolerant Water Vane Actuator**
   - Multiple Stern Planes On Propeller Shroud
   - Produces 90,000 ft-lb. Torque
   - Module Is 14” Wide and 32” Dia.
7. **Large Bow Plane Actuator**
   - Produces 750,000 ft-lb. Torque
   - Module Is 20” Wide and 45” Dia.
   - No Other Bearing/Shaft Support Required
8. **Propeller Pod Drive at 40 RPM**
   - All External To Ship Hull
   - Produces 3,000,000 ft-lb. Torque
   - Module Is 96” Wide and 96” Dia.

GEAR TRAIN COMPARISON



Commercial Drive



Standardized Rotary Actuator

Property	Commercial	New Design	Benefit
Rated Torque	**3, 617 ft.-lb.**	**19,236 ft.-lb.**	**5X**
Torsional Stiffness	**2,531 ft.-lb./Min**	**35,273 ft.-lb./Min**	**14X**
Principal Parts	**14**	**3**	**4.6X**
Principal Bearings	**3**	**1**	**3X**
Ancillary Bearings	**9**	**4**	**2.2X**
Joint Bearing	**No**	**Yes**	**2X**
Design Complexity	**High**	**Low**	**2X**
Temp. Sensitivity	**Medium**	**Low**	**2X**
Other Parameters	O.D. – 18.70” I.D. – 5.91” Ratio – 37.24	O.D. –0 18.0” I.D. –I- 3.0” Ratio – 100	

Note: Volume, Weight, Inertia Comparable In Both Cases
Hypoc cloid Joint Bearing is Very Rugged and Stiff

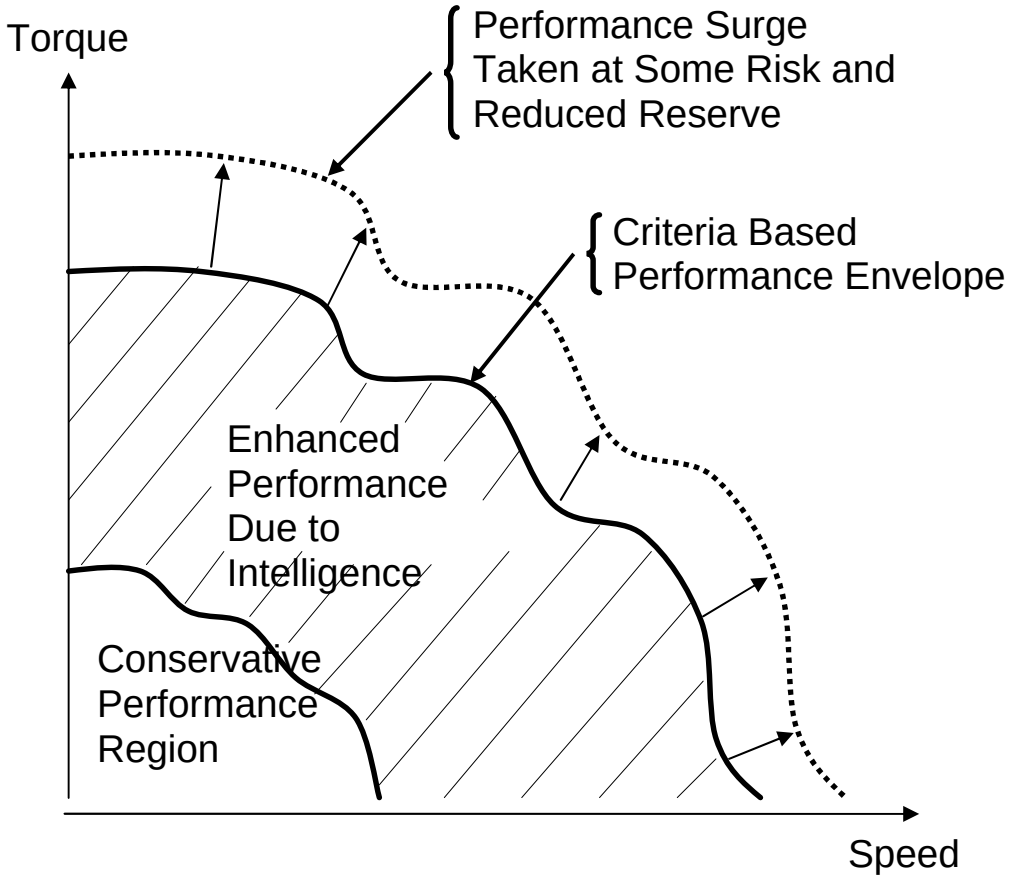
PRELIMINARY SET OF 16 STANDARD ROTARY ACTUATORS

Act. Outer Dia. (In.)	**Act. Length** (In.)	**Reduc-tion Ratio**	**Max. Motor Speed** (RPM)	**Max. Output Speed** (RPM)	**Peak Motor Torque** (Ft.-lb.)	**Peak Output Torque** (Ft.-lb.)
45.00	**18.6**	**100**	**200**	**2**	**7,544**	**754.0 K**
30.00	**12.4**	**100**	**200**	**2**	**3,227**	**323.0 K**
20.00	**10.68**	**100**	**200**	**2**	**1,313**	**131.0 K**
15.00	**8.73**	**100**	**200**	**2**	**780**	**78.0 K**
12.00	**7.27**	**100**	**200**	**2**	**471**	**47.0 K**
10.00	**6.78**	**100**	**1667**	**16.7**	**320**	**32.0 K**
8.00	**5.23**	**100**	**1667**	**16.7**	**171**	**17.1 K**
6.00	**3.92**	**100**	**1667**	**16.7**	**64**	**6.40 K**
5.00	**3.39**	**100**	**1667**	**16.7**	**29.9**	**2.99 K**
4.00	**2.62**	**100**	**1667**	**16.7**	**4.96**	**496**
3.00	**1.24**	**100**	**1667**	**16.7**	**1.474**	**147**
2.00*	**1.31**	**200**	**3300**	**16.7**	**0.153**	**30.6**
1.00*	**0.414**	**400**	**8000**	**20.0**	**8.70E-3**	**3.84**
0.50*	**0.207**	**400**	**12950**	**21.1**	**8.40E-4**	**0.336**
0.33*	**0.136**	**400**	**8000-**	**20.0**	**4.57E-05**	**0.-183**
0.25*	**0.103**	**500**	**10000**	**20.0**	**03.89E-05**	**0.0195**

* These designs are still being evaluated relative to basic requirements.

Figure IV.1.3

Performance Envelope Concept for Intelligent Actuators



- **Control Parameters:** Voltage/Current
- **Performance Parameters:** Response, Torque Margin
- **Performance Threats:** Saturation, Temperature

Figure III.2.7

WEAPON'S ELEVATOR DESIGN

1. KEY TO WEAPON'S HANDLING SYSTEM

- **Bottleneck for Improved Sortie Response**
- **Ancillary Equipment**
  - Upper and Intermediate Ballistic Hatches
  - Loading Doors, Guide Rails, Control Room
  - Cabling, Take-up Drums, Brakes, Safety Devices

2. FUTURE REQUIREMENTS

- **Preserve 15 x 24.5 ft. Elevator Shaft**
- **8.0 Ft. x 19.5 ft. Carriage On Platform**
- **Remove Carriage Both Sideways and Lengthways**
- **Total Carriage/Load Weight of 25,000 lb.**
- **100 H.P. Electro-mechanical Drive System**
- **Fault Tolerance, Improved Availability**
- **Shaft Utilization Enhanced by 5X**

3. DESIGN CONCEPT (Looks Like R.R. System)

- **Carriage Loading Out of Elevator Shaft**
- **Simplified Guide Rails At Corners**
  - Supplies Utilities To Elevator Platform
- **Rotary Gear/Rack Climbing Actuator Modules**
  - One On Each Corner Rail
- **Quick-Change Actuator Attachments to Platform**
- **Rugged Design Intended For Long Service**
  - Condition-Based Maintenance

WEAPON'S ELEVATOR DESIGN (cont.)

4. OPERATION AND MAINTENANCE

- **CBM System To Monitor Performance**
  - Advises On Performance Reserve
  - Requests Actuator Maintenance Or Removal
- **Limp Home Under Partial Or Total Fault**
  - Up To Eight Actuator Modules
  - Actuator Removal Anywhere Along Guide Rails
- **Utilities Through Guide Rails**
  - Separate Power Circuit To Each Actuator
  - Air Cooling To Each Actuator
  - Communications To All Actuators
  - Platform Acts As Utilities Manifold
- **Ballistic Hatch Closed On Demand**
  - Elevator Continues Operation (Above or Below)
  - Folding Hatch Fits In Present Elevator Shaft

5. BENEFITS

- **Potential To Double Sortie Response**
- **No Machinery Room Required**
- **Reduced Manpower And Training Needs**
- **Simplified Maintenance**
- **Enhanced Utilization Flexibility**
- **Warrants Other Weapon's Handling Improvements**
  - Aircraft Weapon's Loading
  - Automated Mobile Platform Transport
  - Weapon's Assembly Cell
  - Automated Warehousing
  - Containerization Standards

Modular Mobile Transport System

(For On-Board Ship Weapon's Handling)

1. EXISTING TRANSPORT SYSTEM

- **Human Operated Lift Trucks**
  - Bulky, Expensive
  - Maintenance Intensive
  - Little Automation Potential
- **Push Carts**
  - Some With Power Assist
- **No Ship Integration**
  - Limited Situation Awareness Data

2. PROPOSED MODULAR PLATFORM

- **Unifying Open Architecture**
  - Plug-and-Play Corner Wheel Modules
  - Battery Operated
  - Computer Navigation
  - Ship-Based Fiduciary Marks
  - Instant Path Planning Reconfigurability
- **Generic Platform Geometry**
  - Small (6"), Medium (12"), Large (18")
  - 2, 3, 4 or More Wheel Modules Per Platform
  - Standardized Quick-Change Interface
  - High Level of Maneuverable Dexterity
  - Ruggedized/No Exposed Wiring/Utilities
  - Vertical Axis Powered By Pancake Actuator
  - Dual Wheels Powered By Cylindrical Actuators

3. SHIP BOARD UTILIZATION

- **Centralized Computer Management**
  - High Level of Ono-Board Intelligence
  - Programmed To Go From Point A to Point B
- **Stored Vertically In Shock Resistant "Closet"**
  - Low Profile Demands Minimal Storage Volume
  - Enhanced Survivability
- **Standardization Reduces Costs**
  - Simplifies Maintenance
  - Minimal Set of Spares

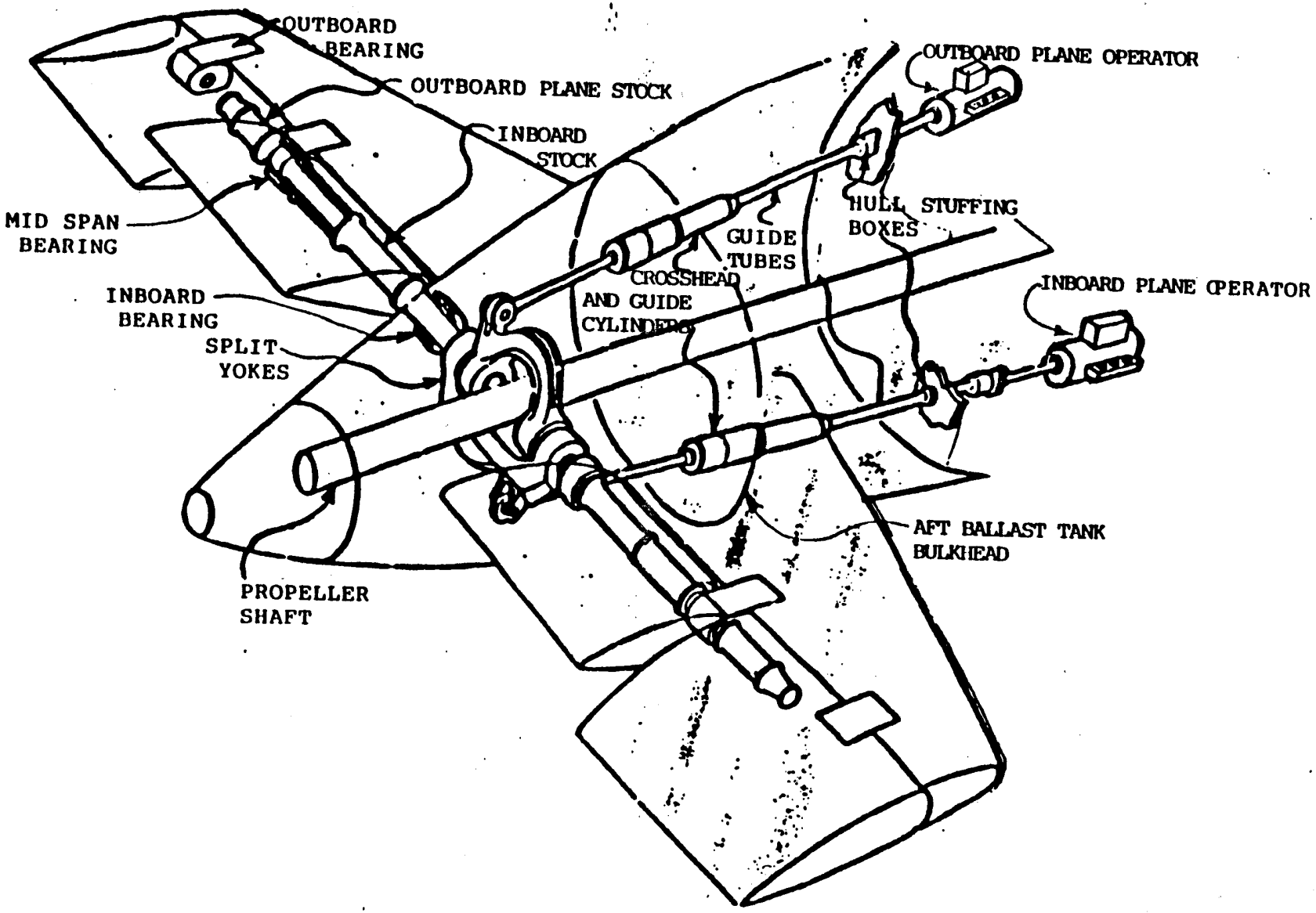
SUBMARINE WATER PLANE ACTUATORS

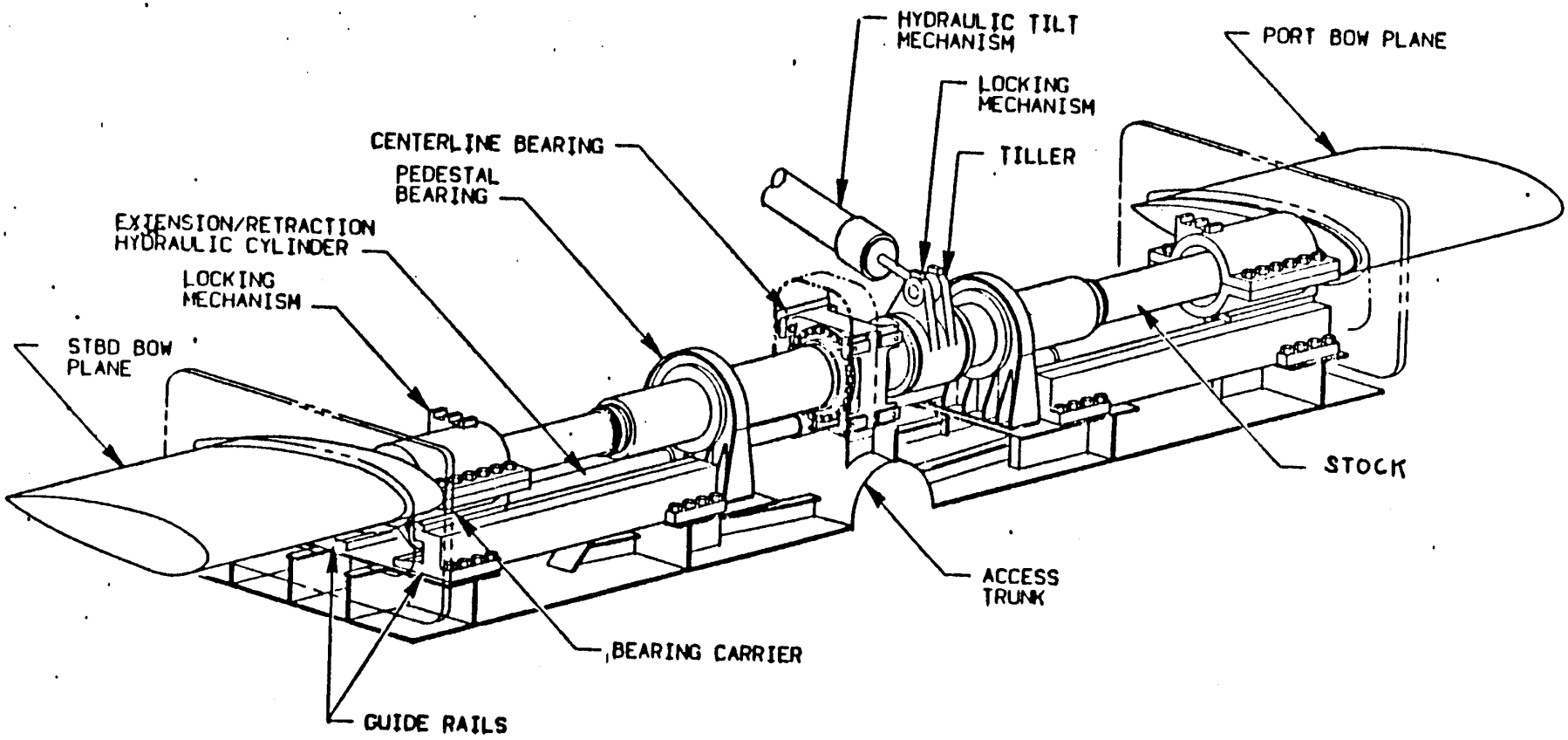
1. **REDUCE STRUCTURAL COMPLEXITY**
   - **Remove Hydraulics**
   - **Reduce Volume And Weight**
   - **Reduce Generated Noise**
   - **Improve Shock Resistance**
   - **Provide Standardized Interfaces**
2. **EXPAND PERFORMANCE ENVELOPE**
   - **Provide Intelligence**
     - Ten Sensor Environment
     - Criteria-Based Control
   - **Condition-Based Maintenance**
     - Timely Repair By Module Replacement
     - Indicates Performance Reserve To Operator
   - **Fault Tolerance**
     - Duality of All Critical Components
     - No Single Point Failures
     - Good Side Compensates For Weak Side
     - Continuous Operation Under A Fault
     - Limp Home at 50% Capacity
3. **ACTUATOR DESIGN CONCEPTS**
   - **Switched Reluctance Motor**
     - Low Speed/High Torque
     - High Efficiency/Low Heat Generation
   - **Rugged Gear Train Design**
     - Low Speed Generates Less Noise
     - Precision (Class 13 to 15) Gears Are Quieter
   - **Special Electronic Controllers**
     - Embedded Intelligence
     - Soft Response Commands
     - Generates Fewer High Harmonics
   - **Shell Design**
     - Rugged/Shock Resistant
     - Absorbs Electrical and Mechanical Signals

SUGGESTED WATER PLANE ACTUATORS

1. **BOW PLANE TILT ACTUATOR**
   - **Use Linear Spindle Screw Actuator**
     - Backfit Hydraulic Actuator
2. **BOW PLANE RETRACTING LINEAR ACTUATOR**
   - **Use Self-Contained Linear Actuator**
     - Backfits Hydraulic Actuator
3. **BOW PLANE DIRECT ROTARY DRIVES**
   - **Replaces Hydraulic Linear Tilt Actuator**
   - **Two Separate Rotary Drives**
     - On Both Sides of Centerline Bearing
     - Provide large Inner Diameter for Shaft
4. **SEPARATE BOW PLANE DIRECT ROTARY DRIVES**
   - **Remove All Tilt Mechanism Structure**
   - **Two Separate Rotary Drives**
     - Place Between Split Bearing Carrier Halves
     - Join With Clutched Drive Tube
     - Umbilical Through Retracting Actuator
5. **SPLIT STERN PLANE DRIVES**
   - **Use Linear Spindle Screw Actuator**
     - Backfit Large Hydraulic Cylinders
     - Preserve All Existing Actuation Structure
6. **MANEUVERING WATER PLANES**
   - **On New Propeller Shroud Housing**
     - 4, 6, or 8 Planes
     - Direct Rotary Drives In Shroud
   - **Potential For Low Dexterity Surfaces**
     - Inside Shroud
     - Improves Propulsion Efficiency
     - Reduces Noise
     - Improves Maneuverability
7. **TRIM TAB ACTUATOR**
   - **Small Trim Tab on Stern Planes**
     - Improves Ship Control
     - Two (or Three) Dual Actuators
     - Fit Within Present Stern Plane Geometry

SPLIT STERN PLANES





RETRACTABLE BOW PLANES
(EXTENDED POSITION)

HIGH TORQUE ROTARY ACTUATOR

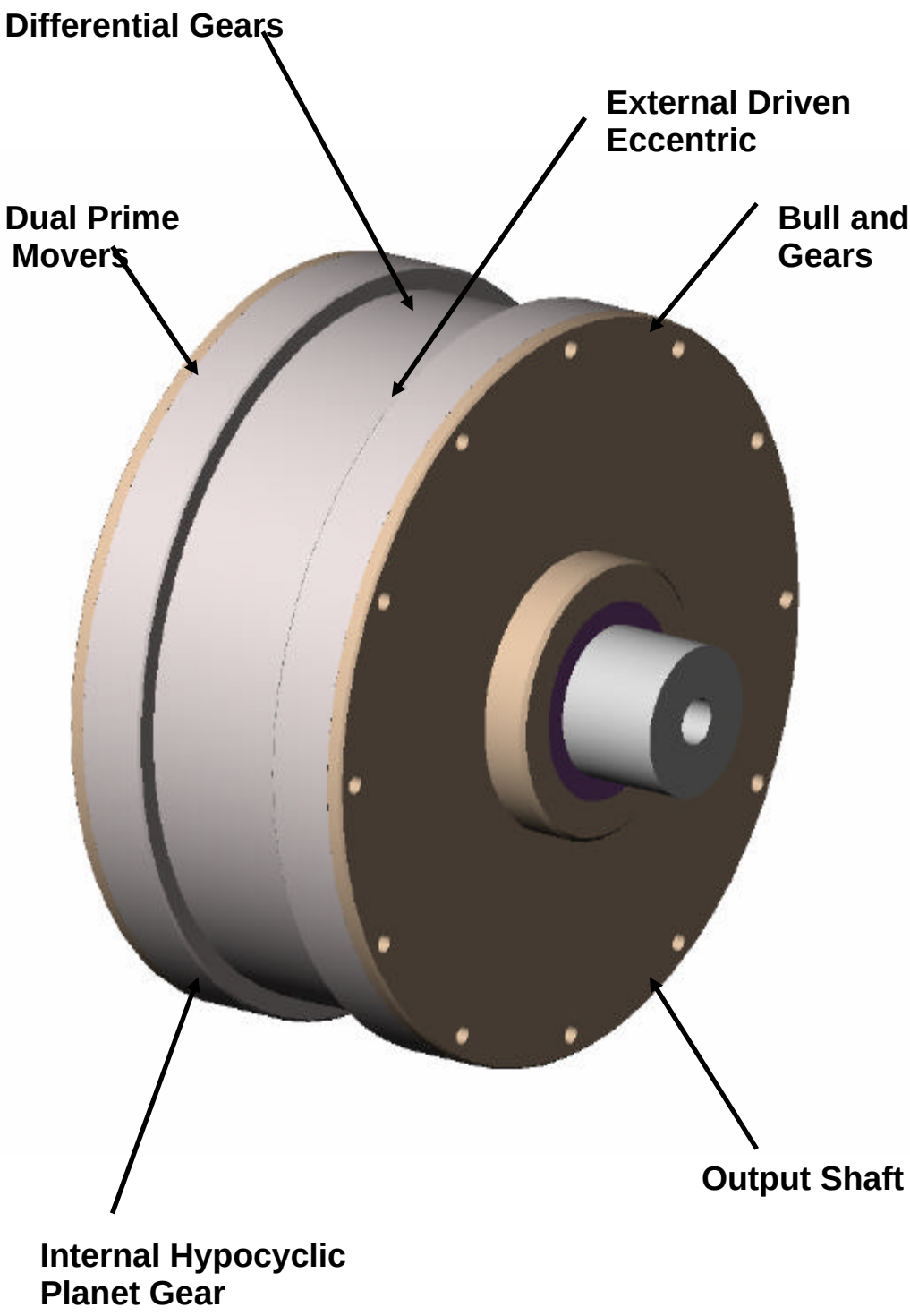
(750,000 ft.-lb. To Drive Submarine Water Vanes)

1. Step Towards All-Electric Ship

- **Replace Hydraulic Cylinders**
  - Old Legacy Technology
  - Noisy/Energy Intensive
  - Hull Seals Required
  - Complex Structural Layout (Linkages, Bearings, Shafts)
- **Self-Contained Drive Module**
  - Provides External Drive
  - Compact/Lightweight
  - Extremely Rugged
  - Water Vane Attaches Directly to Module
  - No Bearing and Shaft Required

2. Proposed Actuator Attributes

- **750,000 FT.-LB. torque Capacity**
  - Surge Demand Is Feasible
- **Width – 24”, Diameter – 45”**
  - Extraordinary Power Density
- **Mounted Outside Ship Hull**
  - Provides Water Vane Bearing Support
  - High Shock Resistant
- **Reduced Emissions**
  - Near Zero Emissions Is Possible
  - High Shock Resistant
  - Intelligence SFW Reduces Motor Noise
  - Exceptionally Quiet Gear Trains



CAD Drawing of High Torque Fault Tolerant Actuator

Fault Tolerant Water Vane Actuator

(Small Output Shaft, 90,000 ft.-lb. Capacity)

General Requirements

Range of Motion	**±35 degrees**
Speed	**1.67 RPM**
Temperature	**-30° to 60° F**
Pressure	**400 psi**

Static Loading (Margin over Recommendations)

Output Torque	**91,500 Ft.-lb.** (+2%)
Vertical Force	**137,000 lb.** (+120%)
Fore/Aft Force	**137,000 lb.** (+4%)
Axial Force	**23,000 lb.** (-18%)

Efficiency

Overall	**67%**
Friction Losses	**8.7%**
Gear Train Losses	**18%**
Prime Mover Losses	**6.3%**

Sizing (Recommended)

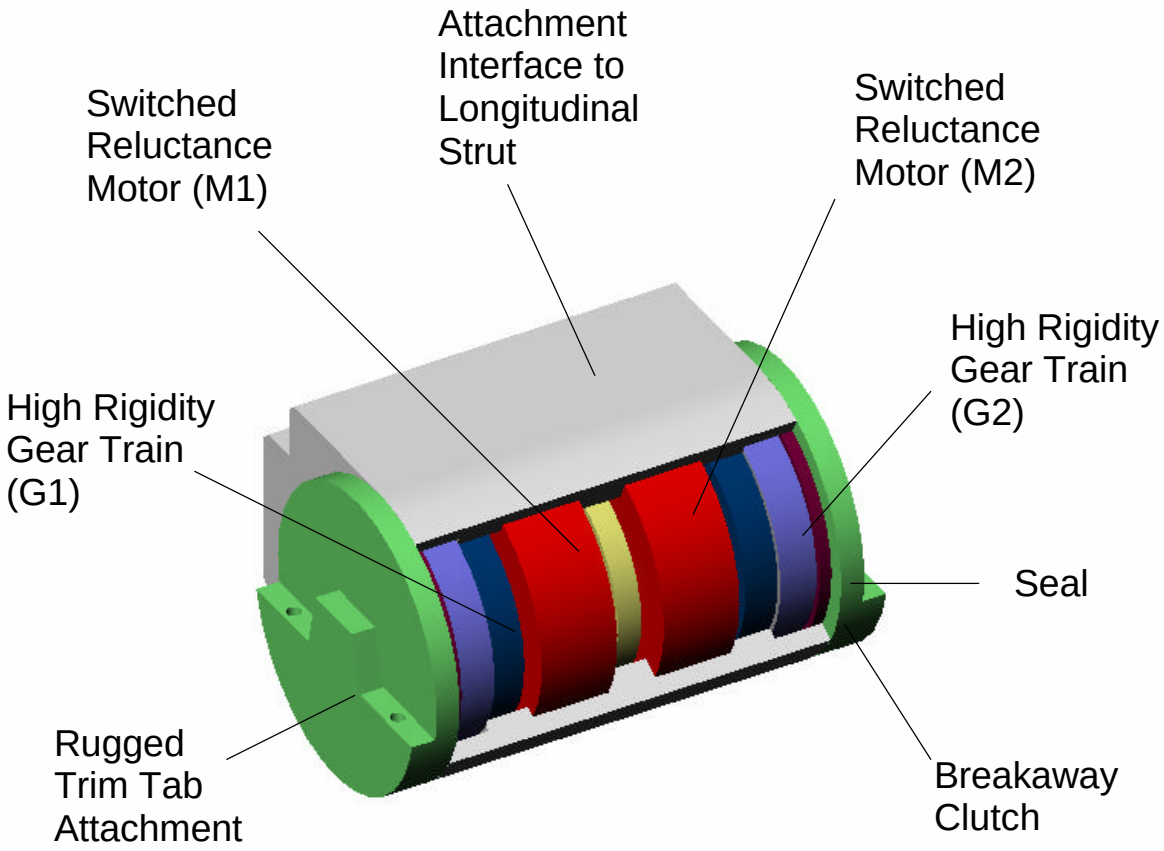
Output Shaft	**8”** (8”)
Width	**14”** (15”)
Diameter	**32”** (36”)
Est. Weight	**3650 lb.** (4330 lb.)

Gearing Issues

Reduction Ratio	**203 to 1**
Circular Arc Gear Teeth	**Desirable**
Expected Noise	**Low**
Wobble Plate Balancing	**Essential**
Friction Losses Study	**Desirable**

Comment: This Design Is Primarily A Torque Producer.

CONCEPT DESIGN FOR DUAL, HIGH STIFFNESS, LOW VOLUME, TRIM TAB ACTUATOR



Max. Speed [deg/sec]	**14**	Diameter [in]	**6.0**
Peak Cont. Torque [in-lb]	**100,000**	Length [in]	**15**
Max. Output Power [hp]	**3.7**	Weight [lb]	**120**

ACTUATOR EVALUATON FOR SUBMARINE TRIM TAB ASSISTED CONTROL

TRIM TAB FUNCTION

- **Attached To Trailing Edges of Existing Control Plane Surfaces**
- **Finer Depth Control, Maneuvering**
- **Lift Enhancement/Reduction**
- **Primary Actuator Torque Reduction**

ACTUATOR REQUIREMENTS

- **Load Capacity** (300,000 in-lb.) (# Actuators per Tab)
- **Compactness** (,800 in^3)
- **Temperature** (-35 to 150^o F)
- **Motion Range** (± 30^o)
- **Complex Duty Cycle**
- **Shock/Vibration** (MilStd)
- **Accuracy** (0.5^o)
- **Actuator Speed** (0.25 rad./sec.)
- **Lock In Place**
- **Reliability** (>10yr)
- **Maintainability**
- **EMI** (MilStd)
- **Fault Tolerance**
- **Weight**
- **Cost**
- **Tech Maturity**
- **Simplicity**
- **Diagnostics**
- **Environmental**

Open Architecture Issues

1. **SMART SHIP PROGRAM** (NRAC STUDIES)
   - **Ship To Warfighter Logistics** (1997)
   - **CVX Flexibility (1997)**
   - **Information Technology Throughout Ship**
   - **Reduce Ship Manning by 50%**
   - **Open Up Mechanical Architecture of Ship**
     - Modular, Upgradable, Maintainability
     - Reduce Total Ownership Cost
     - Build Ship of Standardized Active Components
     - Higher Performance/Reduced Costs
     - Plug-and-Play by Ship Personnel
     - Reduced Set of Logistics Spares
2. **POWER ELECTRONIC BUILDING BLOCKS** (PEBBs)
   - **Openness of Ship Electronics**
   - **Continuous Upgrades**
   - **Reduces Deployment Cost**
   - **Repair By Rapid Module Replacement**
3. **STANDARDIZED ACTUATOR BUILDING BLOCKS** (SABBs)
   - **Openness of Mechanical Architecture of Ship**
     - Minimal Set of Standard Actuator Modules
     - Drive Valves, Doors, Hatches, Etc. Throughout Ship
     - Build On Demand, Open Architecture Robots
   - **Robots For Human Intensive Tasks**
     - Scullery, Stores Handling, Warehousing
     - Bilge Cleaning, Hull Inspection and Cleaning
     - Aircraft Re-Manufacturing
4. **WEAPONS HANDLING**
   - **Now Requires 400(+) Personnel**
     - Forklifts, Weapons Carts
   - **Manpower Reduction Requires Automation**
     - Loading Platform To Aircraft Loading
     - 10 Handling Steps
     - Reduce Manpower to 100(+)
   - **30-Year Benefits**
     - $250,000,000 Cost Savings
     - Reduces Logistics Trail
     - Improves Survivability
     - Reduces Threat of Obsolescence

Weapon's Handling Systems

NINE HANDLING STEPS

- **Mobile Transport Platform**
  - Low Profile (12" high)
  - High Dexterity
  - Eight Identical Actuators
- **Weapons Containerization**
  - Standardized Handling Trays
  - Use Hard Points On Trays
  - Excess Fiduciary Marks
- **Heavy Duty Lifting Manipulators**
  - Lifts Up to 6,000 lbs
- **Precision Dexterous Assembly Manipulators**
  - Accuracy to 0.01 inch
  - Operates In Heavy Seas
  - Specialized Assembly End-Effector Tools
- **Warehousing Systems**
  - 3 DOF Handling Cranes
  - 3 DOF Alley Transporters
- **Medium Build-Up Assembly Cell** (500 lb.)
- **Large Build-Up Assembly Cell** (2000 lb.)
- **Containers For All-Up Rounds**
- **Hangar Aircraft Loading System**
- **Deck Aircraft Loading System**

How Can This Be Done?

1. OPEN ARCHITECTURE COMPUTER CONTROLLERS

- **Performance Increasing**
- **Cost Coming Down**
- **Gigaflop Exists Today**
  - Generalized Operating System
  - Cost of Approximately $10,000

2. COVERS ALL ACTIVE SHIP OPERATIONS

- **Driven By Minimal Set of SABBs**
- **Cost From $2,000 to $12,000**
  - Shock Resistance May Raise Cost
  - Thirteen Distinct Modules Suggested
  - Self Contained Systems
  - Wiring, Motors, Brakes, Sensors, Etc.

3. PLUG-AND-PLAY FOR SABBs

- **Standardized Interfaces**
- **Rapidly Replaced**
  - By Nominally Trained Operator
  - Highly Trained Personnel Unnecessary
- **Minimal Logistics Spares**

4. DIFFUSION OF TECHNOLOGY

- **Rapid Insertion of New Component Technology**
  - Brakes, Sensors, Motors, Etc.
  - Does Not Disturb External Standards
  - Reduced Risk To Decision Maker
  - Encourages Rapid Technical Development
  - Continuous Cost Reduction
  - Continuous Performance Enhancement

5. UNIVERSAL OPERATING SOFTWARE

- **Assemble Systems On Demand**
  - From 1 DOF Up To 20 DOF
- **Open Architecture Software Structure**
  - Upgradable and Downgradable
- **Modern Systems Management**
  - Maximum Performance Envelope
  - Condition-Based Maintenance
  - Fault Tolerance

PROPRIETARY

(Presentation)

NAVY'S ALL-ELECTRIC SHIP PROGRAM

Technology : Intelligent Standardized Actuators

Category : Ship Auxiliaries
Propeller, Water Vanes, Valves, Pumps, Elevators

Principal Investigator:

Prof. D. Tesar, Carol Cockrell Curran Chair in Engineering
Director, Robotics Research Group

In Concert With:

Dr. R. Hebner, Director, Center for Electromechanics
Mr. W. Shutt, Prog. Manager, Applied Research Lab.
Prof. K. Ramu, Electrical Engineering,
Virginia Polytechnic Institute

Topics:

Science Base for Intelligent Actuators
Standardized Actuator Building Blocks
Submarine Water Vane Actuators
Compact Propeller Drives
Shipboard Weapon's Handling
Open Architecture Ship

Robotics Research Group
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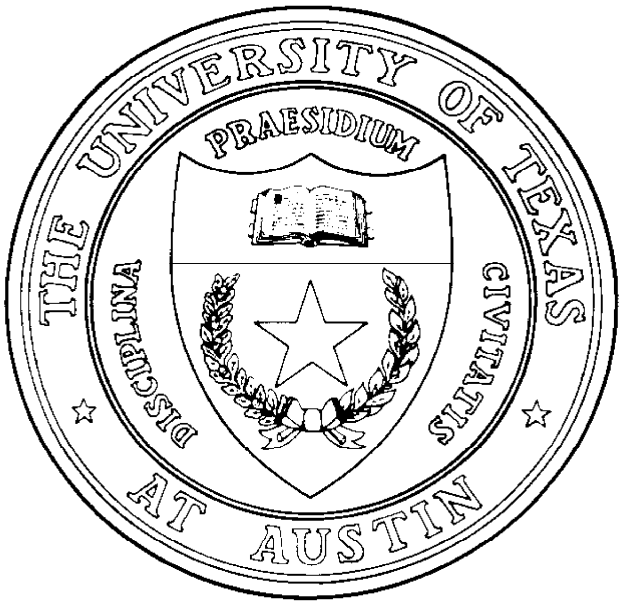
July 5, 2002

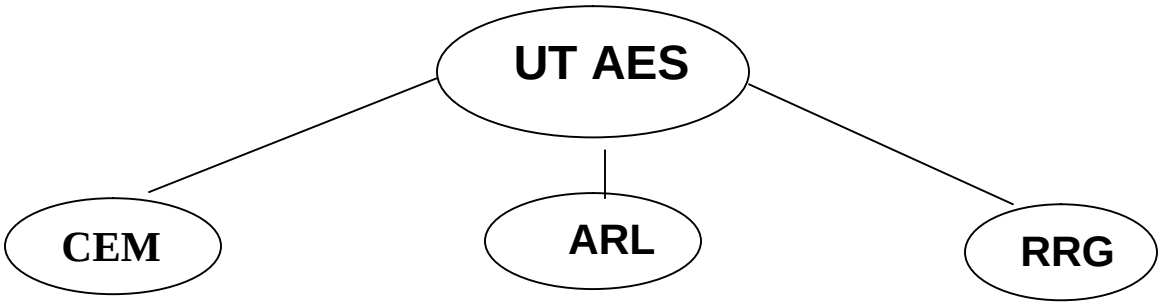


TECHNICAL THRUST

TO PRODUCE MODULAR SYSTEMS WHICH EXHIBIT ADVANCED PERFORMANCE AT REDUCED COSTS WHOSE ARCHITECTURE MATCHES THAT OF TODAY'S COMPUTERS, ALLOWING RAPID REPAIRS AND A REDUCED THREAT OF OBSOLESCENCE.

The University of Texas at Austin
Robotics Research Group
January 1998

The University of Texas
All-Electric Ship Program



Prime Movers

Advanced Materials

Large Actuator Prototypes

Motor/Pumps

Motors/Generators

Flywheel Batteries

Pulsed Power

Aircraft Elevator

Army Applications Requirements

Miniaturized Sensors

Signal Analysis

Real Time Software (Embedded)

CBM (Fault Detection and Identification**)**

Systems Integration

Information Management

Training Regimes

Navy Applications Requirements

Actuator Architecture (Design, Intelligence)

Interface Standards

Actuator Software (Performance Criteria, CBM)

Actuator Testing (Four Test-Beds)

Weapons Elevators

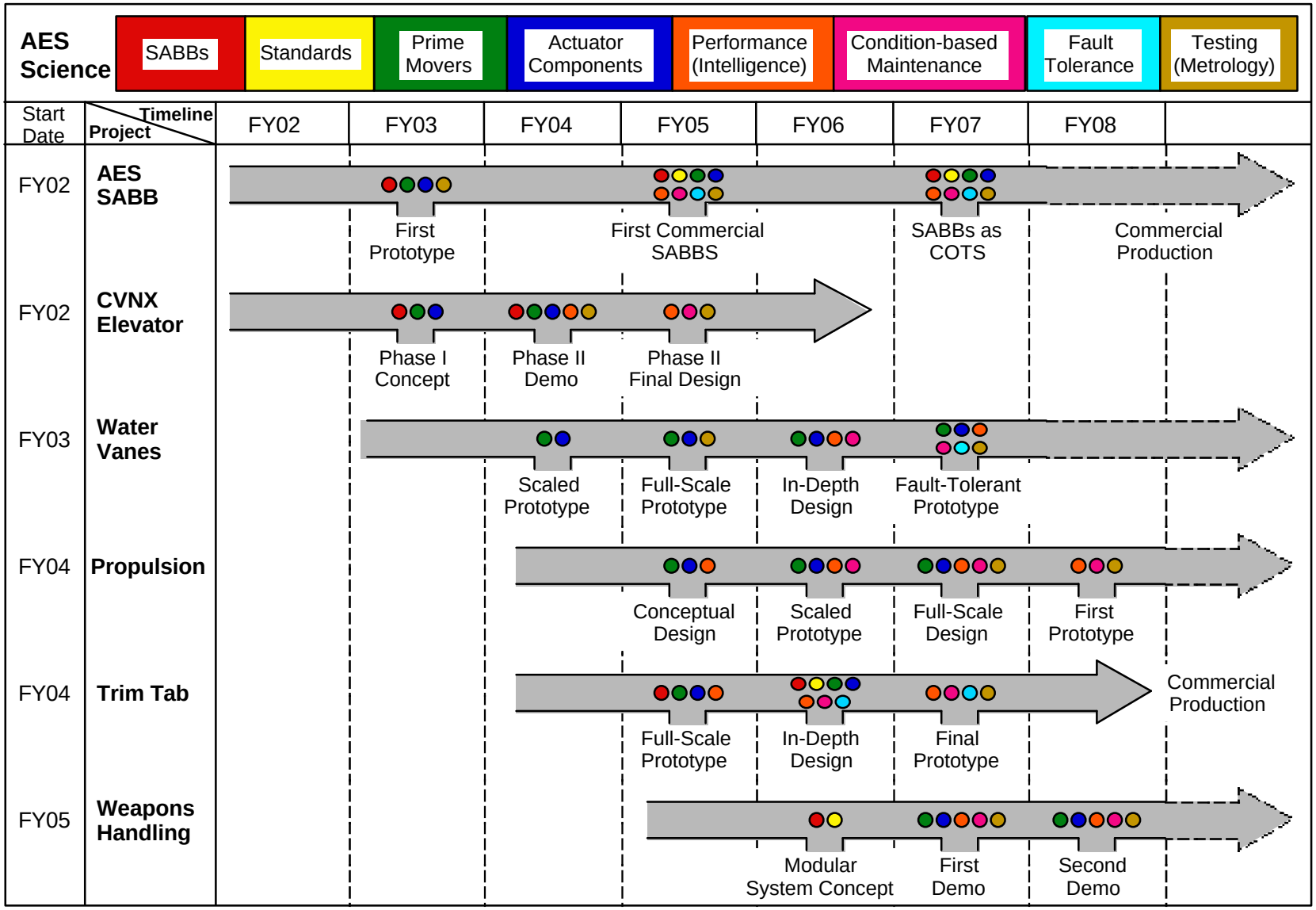
Weapon's Handling

Water Vane and Propulsion Modules

Aerospace Applications Requirements

CEM – Center for Electro-Mechanics
ARL – Applied Research Laboratories
RRG – Robotics Research Group

Overall AES Actuator Project Development Plan



Colored circles (●●●●) in project timeline arrows show relevant AES Science topics for each development phase.

OVERVIEW Of ACTUATOR PROGRAM

1. **Drives Anything That Moves on Ship**
   - **Replaces All Hydraulics**
   - **Standardization Enhances Simplicity**
     - Opens Up Ship Architecture
     - Dual of the PEBB
   - **Dramatically Improves Maintainability**
   - **Exceptional Ruggedness/Survivability**
   - **Potentially Reduces Weight/Volume by 5X**
2. **Further Develop Every Required Technology**
   - **Exceptional Gear Train**
     - 5X Increase In Torque Capacity
     - 15X Increase In Stiffne**ss**
   - **Advanced Prime Mover**
     - Switched Reluctance Motor
     - Modern Electronic Controller
   - **Compact Actuator Design**
     - Only 5 Principal Parts
     - Temperature/Tolerance Insensitive
   - **Intelligence For Enhanced Performance**
     - Eight Orders of Magnitude Improvement Over Two Decades (1990 – 2010)
     - CBM/Fault Tolerance
3. **Eight Distinct Ship Applications**
   - **Submarine Water Vanes**
   - **Propeller Pod Drive Modules**
   - **Weapon's Handling System, ETC.**
4. **Industrial/Commercial Participation**
   - **10 Interested Corporations**
     - Rockwell, Timken, Curtiss-Wright, Boeing, Newport News, etc.

Open Architecture Objectives

1. BENEFITS

- **Reduced Total Ownership Costs**
- **Reduced Manning**
- **Enhanced Survivability**
- **Increased Fighting Capacity**
- **Reduced Logistics Trail**
- **More Rapid Upgrades**
- **Reduced Threat of Obsolescence**

2. PRINCIPAL ACTUATORS

- **Replace All Hydraulics**
- **Water Vane Operation**
  - Rotary
  - Linear
- **Propulsion Module**
  - Motor/Gear Combination
  - External Pod Configuration

3. AUTOMATION OPPORTUNITIES

- **Launch Systems**
- **Control Surfaces**
- **Firemain Reconfiguration**
- **Valves, Doors, Hatches, Etc.**

4. ROBOTIC APPLICATIONS

- **Weapons Handling/Aircraft Preparation**
- **Stores Handling and Warehousing**
- **Hull Inspection and Maintenance**
- **Aircraft Refueling/Firefighting**
- **Scullery/Bilge Cleaning**

Future Ship Needs Provided By SABB's

(Navy Requirements)

1. COMBAT EFFECTIVENESS

Sustainability	**Resupply SABB's From Minimal Set of Spares**
Maneuverability	**Reduced Weight and Volume, More Accurate Control of Submarine Water Vanes**
Ordnance Load-Out	**Automate Weapon's Handling And Make-up**
Sortie Response	**Aircraft Carrier Weapon's Elevator Utilization Up By 5 X**

2. INCREASE SURVIVABILITY

Damage Tolerance	**Design For High Level Of Ruggedness And Shock Resistance, Fault Tolerance**
Damage Control	**All Ancillary Components Associated With Hydraulics Removed From Ship**
In-Situ Replacement	**Plug-and-Play Replacement From Spares Immediately After Hit**
Signatures	**Concentrate All Sciences To Reduce Signatures From Minimal Set of SABB's for All Navy Applications**

Figure IV.1.1

Future Ship Needs Provided By SABB's
(Navy Benefits)

3. REDUCE TOTAL OWNERSHIP COST
(Acquisition)

RDT&E	**Concentrate Development On Minimal Set Of SABB's**
Production Cost	**Standardize SABB Production, Leverage Industrial COTS**
Design Costs	**In-Depth Design Of Minimal Set Of SABB's**
Acceptance Costs	**In-Depth Certification Of Minimal Set Of SABB's**

4. REDUCE TOTAL OWNERSHIP COST
(Operations And Support)

Manning & Training	**Finite Number Of Standardized SABB's**
Repair & Maintenance	**Plug-and-Play, Quick Change Out At Sea**
Upgrades & Modernization	**Immediate Tech Mods At Sea By Nominally Trained Technicians**
Operational Status	**Conditioned-Based Maintenance For Continuous Awareness of Performance Reserve**

Figure IV.1.2

SHIP ACTUATOR TECHNOLOGY BASELINE

I. PRESENT BASELINE

- **Most Actuators Are Hydraulic**
  - Connections, Piping, Fluids
  - Pumps, Valving, Reservoirs
  - Circulation Systems
  - High Maintenance History
- **Virtually No Situational Awareness**
  - Independent Operation(s)
  - Manual Controls
  - Minimal Sensors
  - Nominal Performance

II. ONR EMPHASIS

- **Fight Through** (Survivability)
- **Reconfigurability** (Fault Tolerance)
- **Reduced Weight** (Volume)
- **High Efficiency** (Reduced Thermal Loads)
- **Reduced Manpower** (Simplified Training)
- **Reduced Emissions** (All Types)

III. EXAMPLE FUTURE BASELINE

- **Stern Planes** (Present)
  - Linkages, Bearings, Hydraulics, Pistons, Hull Penetrations
- **Water Vanes** (Future)
  - Reduce Weight/Volume
  - Take Actuation Outside Hull
  - Improve Shock Resistance
  - Improve Quietness
  - Distributed Small Water Vanes
  - Trim Tabs
- **Propulsion** (Future)
  - External Pods/Quick Change?
  - Directed Force Vector/Steering?
  - Gimbaled Pod?
  - Universal Joint Pod Support?

Overall Contribution of University of Texas Robotics Research Group

1. **ACTUATOR SCIENCE BASE** (SABB'S)
   - **Standardized Interface / Optimum Design**
   - **Maximum Performance Envelope**
   - **10 Sensor Environment**
   - **Condition-Based Maintenance**
   - **Fault Tolerance**
2. **AUTOMATION/WEAPONS HANDLING**
   - **Build Systems On Demand**
   - **Minimal Set** (13) **of SABB's**
   - **Reduce Manpower by 300%**
   - **$250 Million Cost Savings Per Aircraft Carrier**
3. **MODERN WEAPONS ELEVATOR CONCEPT**
   - **Improves Utilization by 500%**
   - **Climbing Gear/Rack Actuators**
   - **Condition-Based Maintenance For All Actuators**
   - **Open Architecture Carriage Platform**
   - **No Cables, No Umbilical, No Machinery Room**
   - **New Ballistics Hatch**
4. **MOBILE PLATFORM FOR WEAPONS TRANSPORT**
   - **Modular/Standardized Wheel Module**
   - **12" Total Height**
   - **Automated Shipboard Navigation**
   - **Rugged/High Survivability**
   - **Replaces Lift Trucks and Push Carts**

Overall Contribution (cont.)

5. ALL-ELECTRIC SUBMARINE WATER PLANE ACTUATORS

- **Remove All Hydraulics**
- **Torque Capacity Up To 750,000 ft.-lb.**
- **Fault Tolerance/High Survivability**
- **Rugged / Shock Resistant Designs**
- **Reduced Volume/Weight/Complexity**

6. FAULT TOLERANT WATER VANE DRIVES

- **For Future Submarine Applications**
- **90,000 ft.-lb. Torque**
- **14” Wide / 32” In Diameter**
- **Dual Pancake Switched Reluctance Motors**
- **Rugged / Quiet Gear Train**

7. TRIM TAB WATER VANE ACTUATOR

- **For Precision Submarine Maneuvers**
- **Trim Tab on Edge of Water Vane**
- **6x Redundancy / Fault Tolerance**
- **Exceptional Torque-To-Weight Ratio**
- **Exceptional Stiffness / Ruggedness**

8. EXTERNAL ELECTRIC SHIP PROPELLER POD DRIVE

- **3,000,000 ft.-lb. Torque at 40 RPM**
- **20,000 HP / 20,000 RPM Motor**
- **Extremely Compact / Rugged 500-to-1 Gear Train**
- **Self-Contained Replaceable Module** (at Sea)
- **Enhances Ship Availability**

9. ELECTRICAL-MECHANICAL CATAPULT

- **Dual High Speed Flywheels** (10,000 RPM)
- **Dual Clutches Drive Dual Gear Trains**
- **Differential Drives Cable Drum**
- **Controlled Acceleration of Aircraft**
- **Exceptional Compactness / Weight**
- **Reduced Volume/Weight/Complexity**

UT AUSTIN LISTING OF MAJOR REPORTS

(126 Since 1985)

	TOPIC	NO. OF REPORTS
1.	Assessment of Application Requirements	6
2.	Kinematic Design of Manipulator Systems	5
3.	Dynamic Modeling Of Manipulator Systems	10
4.	Metrology and Measurement Of Manipulator Systems	4
5.	Control of Manipulator Systems	15
6.	Operational Software for Manipulator Systems	23
7.	Actuator Development	34
8.	Structural Design Of Manipulator Systems	14
9.	Electronic Controller Development	11
10.	Integrated Manufacturing Cells	4

ACTUATOR TASK DISTRIBUTION

	AES (Science)	URPR (Rugged)	Boeing (Fault Tolerance)	VASCIC (Standard)	PANTEX (Light Duty)
Gearing	**Park** (60%)	**Park** (20%)		**Park** (20%)	
SRM (Others)	**Ashok** (40%)		**Ashok** (20%)	**Ashok** (20%)	
Criteria	**Ashok** (20%)				
	Yoo (40%)				
	Song (30%)				
	Linsey (50%)				
Design	**Shin** (20%)	**Shin** (20%)		**Janardhan** (60%)	**X1** (30%)
	Gloria (40%)		**Gloria** (60%)	**Banks** (20%)	
Sensors	**X1** (40%)	**Hvass** (10%)	**Hvass** (10%)	**Hvass** (10%)	
Operations SFW	**Song** (20%)		**Song** (30%)		
CBM	**Hvass** (70%)				
	Song (20%)				
Fault Tolerance	**Boztas** (30%)		**Boztas** (30%)		
Components	**Janardhan** (40%)		**Boztas** (20%)		**Boztas** (20%)
	Kang (20%)		**Kang** (20%)	**Kang** (20%)	
Interfaces	**Shin** (40%)	**Shin** (20%)		**Banks** (20%)	
Testing	**Kang** (40%)	**Yoo** (50%)	**Yoo** (10%)		
Navy Integration	**Banks** (60%)				
Prototypes	**Vaculik** (20%)	**Vaculik** (80%)		**X1** (30%)	**Linsey** (50%)
	7.00	**2.00**	**2.00**	**2.00**	**1.0** **(14 Total)**

Note: In January 2003, we may add **X3** in Components and Light Duty Actuators and move Boztas to Design work under Boeing.

Potential Industrial Partners For Intelligent Actuator Development

	PARTNER	APPLICATIONS
1.	**Newport News Shipbuilding**	Submarine Water Vane Actuators Aircraft Carrier Weapon's Handling Improved Elevator Technology
2.	**AMSEC**	Improved Ship Maintenance and Spares Logistics
3.	**Rosenblatt**	Open Architecture Ship Standardized Actuators For the Navy
4.	**Unidynamics**	Ship Support Systems (Doors, Hatches, Elevators, Etc.)
5.	**Rockwell**	Ship Electric Drives Advanced Prime Movers
6.	**Timken**	Standardized Actuators Special Bearings and Gear Trains Distributed Sensor Arrays
7.	**Boeing**	Fault Tolerant Aircraft Actuators
8.	**Curtiss-Wright**	Actuators For Aerospace Industry
9.	**Bechtel**	All-Electric Construction Equipment
10.	**General Motors**	Open Architecture Mfg. Cells Electric Wheel Drives

RESEARCH PROGRAM AT UT AUSTIN

1.	**NAVY** (June 2002) (Fall 2004)	- **All-Electric Ship Initiative** RRG on Actuator Science Actuator Development	$280K/1st Yr. $2.0 mil/Yr.
2.	**Aircraft Carrier** (Fall 2002)	- **Consortium of Universities To Provide Weapons and Stores Handling** (Navy, NNS) (Virginia, VA Tech, Old Dominion)	$100K/1st Yr. $1.45 mil ($4 mil)
3.	**DOE** (Continuing)	- **Dismantle Nuclear Facilities Nuclear Weapons Disposal Rugged Actuator Development**	$865 K/yr.
4.	**TEXAS ATP** (Fall 2001)	- **Machine Performance Criteria Development, Testing and Demonstration**	$250 K (2 yrs.)
5.	**FAA** (Sum. 2003)	- **Commercial Aircraft Safety** (Consortium of UTexas, UTenn, FA&M, VPI)	$1.0 mil/yr. ($2.5 mil/yr.)
6.	**Aircraft Actuators** (Spring 2002)	- **Boeing Organized Fault Tolerant Actuator Prototype** (With VPI, Approach Air Force)	$100K ($500K)
7.	**DOE** (Fall 2002)	- **Nuclear Weapons Dismantle-ment Operations** (Pantex)	$200K/yr.
8.	**International University**	- **Open Architecture Manufacturing Cells** (UT Austin, Prague, Singapore, et al)	(?)

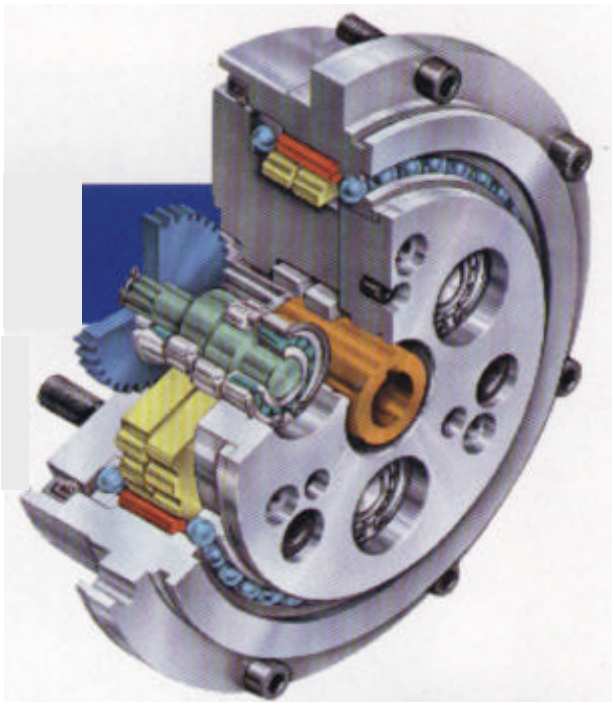
ACTUATOR SCIENCE BASE DEVELOPMENT

1. **Standardized Actuators**
   - Drives Everything That Moves
   - Emphasis On Ruggedness/Simplicity
   - Reduces Weight/Volume By 5X
2. **Open-Architecture Interfaces**
   - Plug-and-Play By Nominal Technician
   - Minimal Set of Actuators (13)
3. **High Performance Based On Intelligence**
   - Expanded Performance Envelope (3X)
   - Embed 10 Sensors In All Actuators
4. **Exceptional Component Technologies**
   - Gear Trains, Motors, Controllers, Sensors
   - Integrated In Full Actuator Architecture
5. **Condition Based Maintenance**
   - Model Based/Finite Fault Tree
   - No False Alarms
6. **Operational Criteria**
   - Criteria Balanced For Best Performance
   - Actuator Operating Software
7. **Fault Tolerance/Reconfiguration**
   - Survival Under A Fault/Failure
   - Force and Velocity Summing Configurations
8. **Test Regime**
   - Four Distinct Test-Beds
   - Document Performance “As Built”
9. **Interface To Ship Control System**
   - Dual of PEBB Concept
   - Situational Awareness To Control Centers
10. **Actuator Prototype Development**
    - In Concert With Industry
    - Meet Customer Requirements
    - Certification By Carderrock/Philadelphia

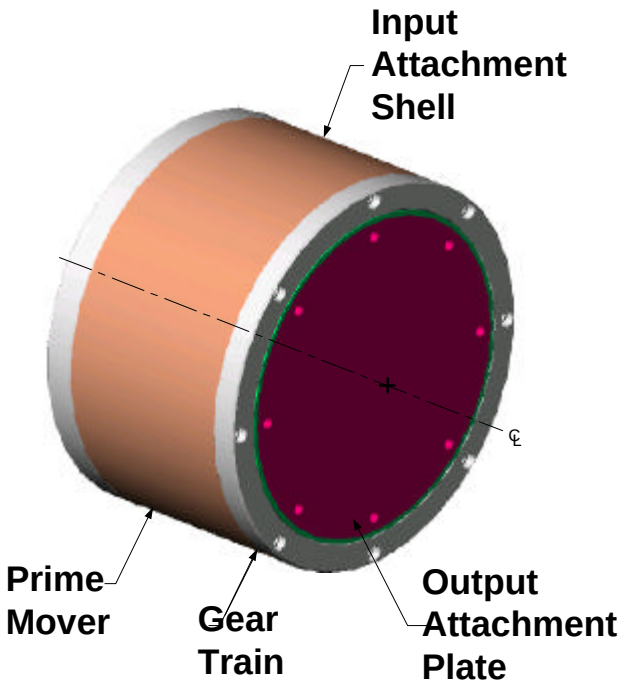
SHIP APPLICATIONS UNDER DEVELOPMENT

1. **Ruggedized Standard Actuator Module**
   - Replaces All Hydraulics
   - Compact, Stiff, Shock Resistant
   - Exceptional Performance/Intelligence
   - Maintenance By Unskilled Technician
2. **Water Vane Trim Tab**
   - Provides Precision Maneuver Control
   - Fault Tolerant Rotary Module (6” x 15”)
   - 3 Modules Produce 25,000 ft-lb. Torque
3. **Open Architecture Weapons Elevator**
   - Elevator Utilization Up By 5 X
   - Removes All Machinery Room Space
   - Doubles Load Capacity
4. **Mobile Weapon’s Transport Platform**
   - Modular/Low Profile of 12”
   - Intelligent/Autonomous Navigation
5. **Open Architecture Weapon’s Handling System**
   - Robots, Warehousing, Weapon’s Assembly, etc.
   - Made Up of 13 Standardized Actuators
   - Reduces Manpower By 4X
   - Saves $350,000,000 over 50Year Life Of Carrier
6. **Fault Tolerant Water Vane Actuator**
   - Multiple Stern Planes On Propeller Shroud
   - Produces 90,000 ft-lb. Torque
   - Module Is 14” Wide and 32” Dia.
7. **Large Bow Plane Actuator**
   - Produces 750,000 ft-lb. Torque
   - Module Is 20” Wide and 45” Dia.
   - No Other Bearing/Shaft Support Required
8. **Propeller Pod Drive at 40 RPM**
   - All External To Ship Hull
   - Produces 3,000,000 ft-lb. Torque
   - Module Is 96” Wide and 96” Dia.

GEAR TRAIN COMPARISON



Commercial Drive



Standardized Rotary Actuator

Property	Commercial	New Design	Benefit
Rated Torque	**3, 617 ft.-lb.**	**19,236 ft.-lb.**	**5X**
Torsional Stiffness	**2,531 ft.-lb./Min**	**35,273 ft.-lb./Min**	**14X**
Principal Parts	**14**	**3**	**4.6X**
Principal Bearings	**3**	**1**	**3X**
Ancillary Bearings	**9**	**4**	**2.2X**
Joint Bearing	**No**	**Yes**	**2X**
Design Complexity	**High**	**Low**	**2X**
Temp. Sensitivity	**Medium**	**Low**	**2X**
Other Parameters	O.D. – 18.70” I.D. – 5.91” Ratio – 37.24	O.D. –0 18.0” I.D. –I- 3.0” Ratio – 100	

Note: Volume, Weight, Inertia Comparable In Both Cases
Hypoc cloid Joint Bearing is Very Rugged and Stiff

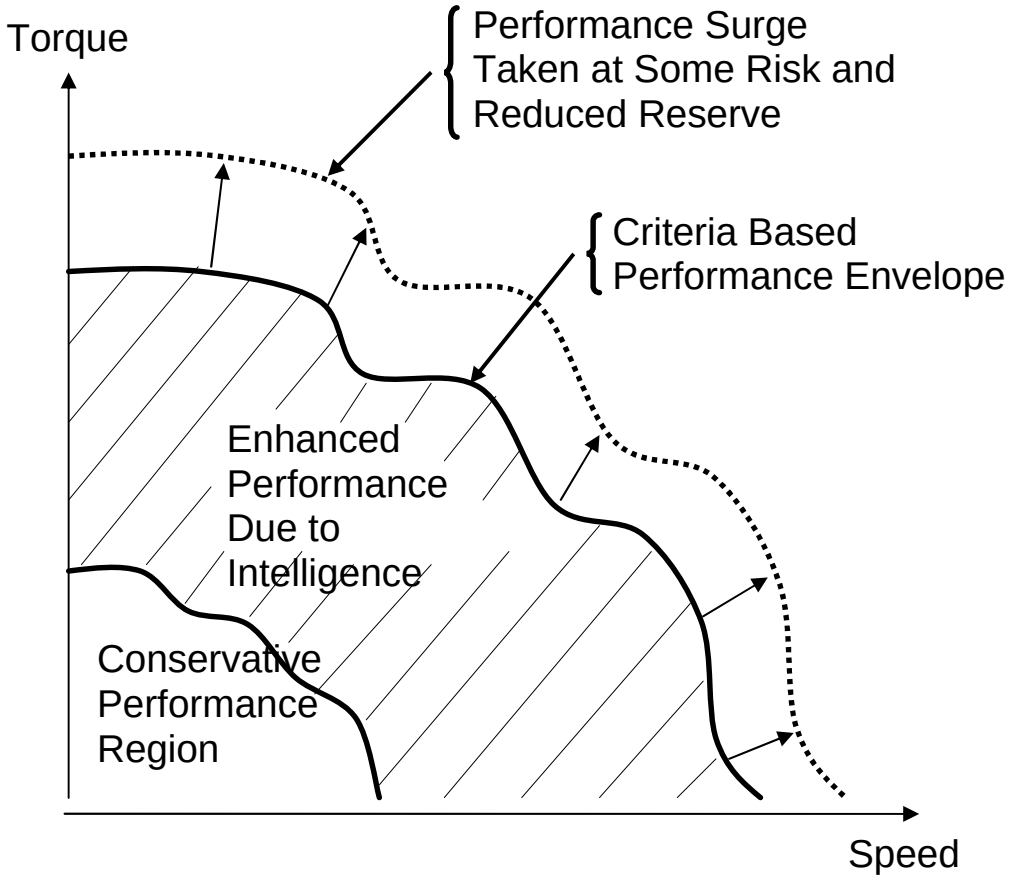
PRELIMINARY SET OF 16 STANDARD ROTARY ACTUATORS

Act. Outer Dia. (In.)	**Act. Length** (In.)	**Reduc-tion Ratio**	**Max. Motor Speed** (RPM)	**Max. Output Speed** (RPM)	**Peak Motor Torque** (Ft.-lb.)	**Peak Output Torque** (Ft.-lb.)
45.00	**18.6**	**100**	**200**	**2**	**7,544**	**754.0 K**
30.00	**12.4**	**100**	**200**	**2**	**3,227**	**323.0 K**
20.00	**10.68**	**100**	**200**	**2**	**1,313**	**131.0 K**
15.00	**8.73**	**100**	**200**	**2**	**780**	**78.0 K**
12.00	**7.27**	**100**	**200**	**2**	**471**	**47.0 K**
10.00	**6.78**	**100**	**1667**	**16.7**	**320**	**32.0 K**
8.00	**5.23**	**100**	**1667**	**16.7**	**171**	**17.1 K**
6.00	**3.92**	**100**	**1667**	**16.7**	**64**	**6.40 K**
5.00	**3.39**	**100**	**1667**	**16.7**	**29.9**	**2.99 K**
4.00	**2.62**	**100**	**1667**	**16.7**	**4.96**	**496**
3.00	**1.24**	**100**	**1667**	**16.7**	**1.474**	**147**
2.00*	**1.31**	**200**	**3300**	**16.7**	**0.153**	**30.6**
1.00*	**0.414**	**400**	**8000**	**20.0**	**8.70E-3**	**3.84**
0.50*	**0.207**	**400**	**12950**	**21.1**	**8.40E-4**	**0.336**
0.33*	**0.136**	**400**	**8000-**	**20.0**	**4.57E-05**	**0.-183**
0.25*	**0.103**	**500**	**10000**	**20.0**	**03.89E-05**	**0.0195**

* These designs are still being evaluated relative to basic requirements.

Figure IV.1.3

Performance Envelope Concept for Intelligent Actuators



- **Control Parameters:** Voltage/Current
- **Performance Parameters:** Response, Torque Margin
- **Performance Threats:** Saturation, Temperature

Figure III.2.7

WEAPON'S ELEVATOR DESIGN

1. KEY TO WEAPON'S HANDLING SYSTEM

- **Bottleneck for Improved Sortie Response**
- **Ancillary Equipment**
  - Upper and Intermediate Ballistic Hatches
  - Loading Doors, Guide Rails, Control Room
  - Cabling, Take-up Drums, Brakes, Safety Devices

2. FUTURE REQUIREMENTS

- **Preserve 15 x 24.5 ft. Elevator Shaft**
- **8.0 Ft. x 19.5 ft. Carriage On Platform**
- **Remove Carriage Both Sideways and Lengthways**
- **Total Carriage/Load Weight of 25,000 lb.**
- **100 H.P. Electro-mechanical Drive System**
- **Fault Tolerance, Improved Availability**
- **Shaft Utilization Enhanced by 5X**

3. DESIGN CONCEPT (Looks Like R.R. System)

- **Carriage Loading Out of Elevator Shaft**
- **Simplified Guide Rails At Corners**
  - Supplies Utilities To Elevator Platform
- **Rotary Gear/Rack Climbing Actuator Modules**
  - One On Each Corner Rail
- **Quick-Change Actuator Attachments to Platform**
- **Rugged Design Intended For Long Service**
  - Condition-Based Maintenance

WEAPON'S ELEVATOR DESIGN (cont.)

4. OPERATION AND MAINTENANCE

- **CBM System To Monitor Performance**
  - Advises On Performance Reserve
  - Requests Actuator Maintenance Or Removal
- **Limp Home Under Partial Or Total Fault**
  - Up To Eight Actuator Modules
  - Actuator Removal Anywhere Along Guide Rails
- **Utilities Through Guide Rails**
  - Separate Power Circuit To Each Actuator
  - Air Cooling To Each Actuator
  - Communications To All Actuators
  - Platform Acts As Utilities Manifold
- **Ballistic Hatch Closed On Demand**
  - Elevator Continues Operation (Above or Below)
  - Folding Hatch Fits In Present Elevator Shaft

5. BENEFITS

- **Potential To Double Sortie Response**
- **No Machinery Room Required**
- **Reduced Manpower And Training Needs**
- **Simplified Maintenance**
- **Enhanced Utilization Flexibility**
- **Warrants Other Weapon's Handling Improvements**
  - Aircraft Weapon's Loading
  - Automated Mobile Platform Transport
  - Weapon's Assembly Cell
  - Automated Warehousing
  - Containerization Standards

Modular Mobile Transport System

(For On-Board Ship Weapon's Handling)

1. EXISTING TRANSPORT SYSTEM

- **Human Operated Lift Trucks**
  - Bulky, Expensive
  - Maintenance Intensive
  - Little Automation Potential
- **Push Carts**
  - Some With Power Assist
- **No Ship Integration**
  - Limited Situation Awareness Data

2. PROPOSED MODULAR PLATFORM

- **Unifying Open Architecture**
  - Plug-and-Play Corner Wheel Modules
  - Battery Operated
  - Computer Navigation
  - Ship-Based Fiduciary Marks
  - Instant Path Planning Reconfigurability
- **Generic Platform Geometry**
  - Small (6"), Medium (12"), Large (18")
  - 2, 3, 4 or More Wheel Modules Per Platform
  - Standardized Quick-Change Interface
  - High Level of Maneuverable Dexterity
  - Ruggedized/No Exposed Wiring/Utilities
  - Vertical Axis Powered By Pancake Actuator
  - Dual Wheels Powered By Cylindrical Actuators

3. SHIP BOARD UTILIZATION

- **Centralized Computer Management**
  - High Level of Ono-Board Intelligence
  - Programmed To Go From Point A to Point B
- **Stored Vertically In Shock Resistant "Closet"**
  - Low Profile Demands Minimal Storage Volume
  - Enhanced Survivability
- **Standardization Reduces Costs**
  - Simplifies Maintenance
  - Minimal Set of Spares

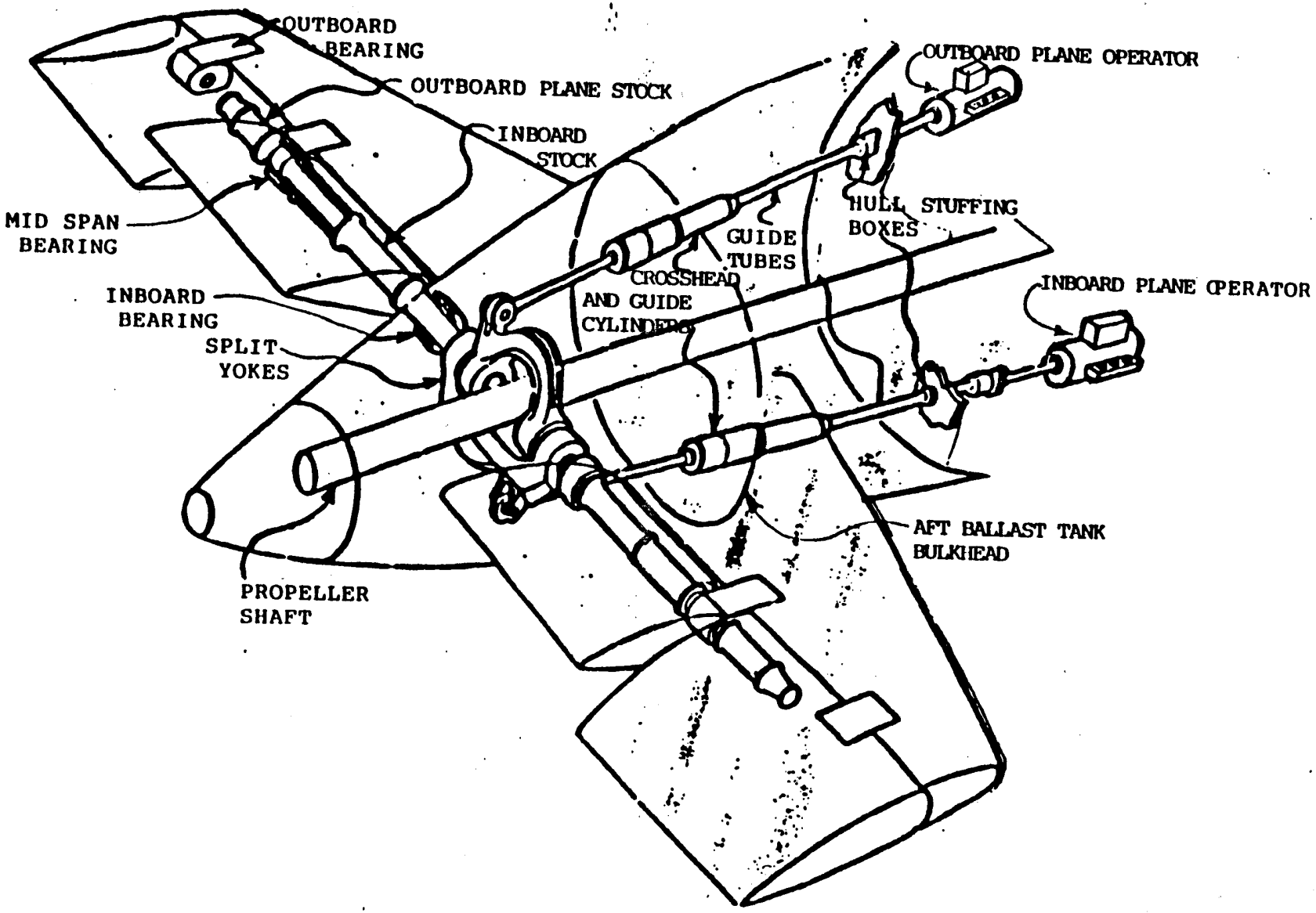
SUBMARINE WATER PLANE ACTUATORS

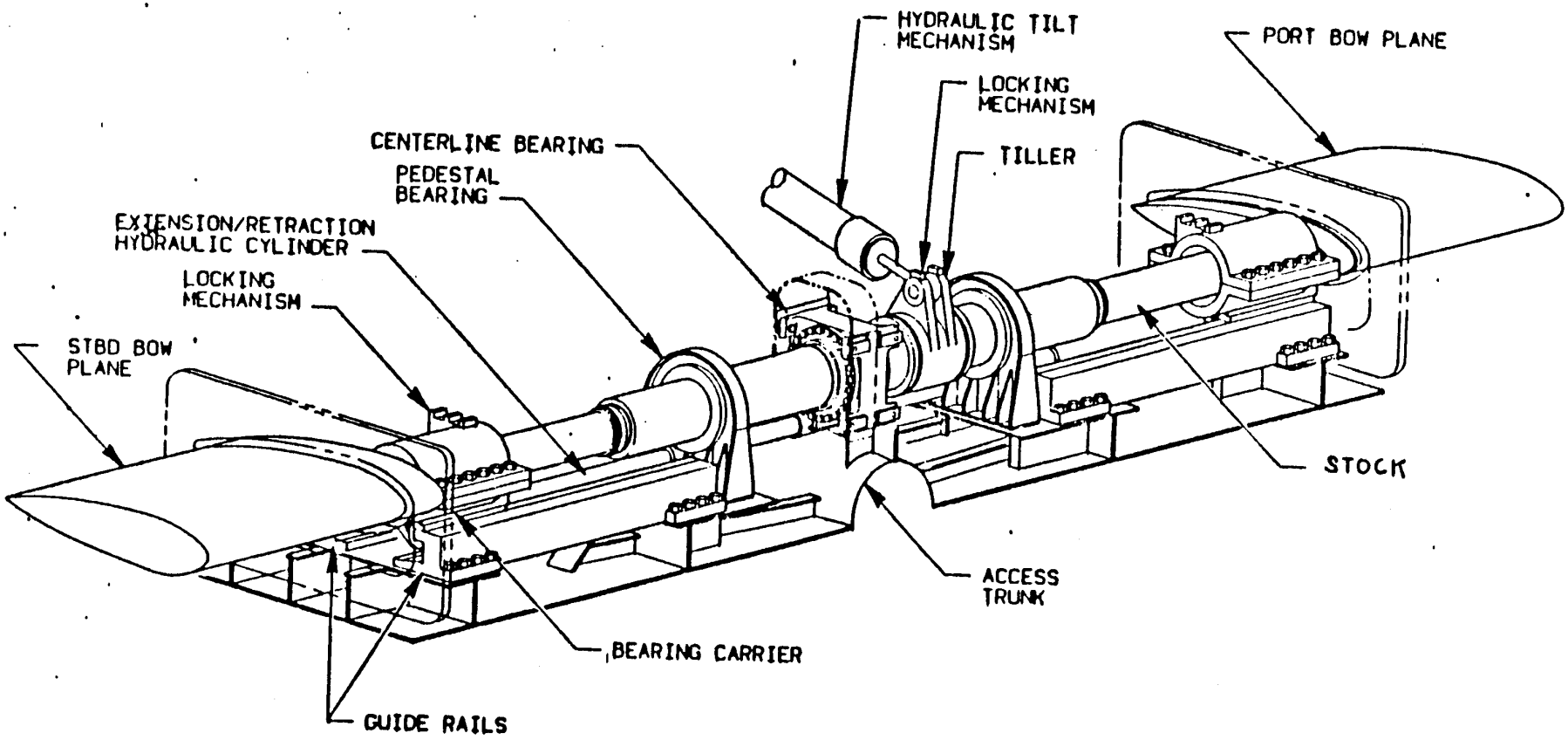
1. **REDUCE STRUCTURAL COMPLEXITY**
   - **Remove Hydraulics**
   - **Reduce Volume And Weight**
   - **Reduce Generated Noise**
   - **Improve Shock Resistance**
   - **Provide Standardized Interfaces**
2. **EXPAND PERFORMANCE ENVELOPE**
   - **Provide Intelligence**
     - Ten Sensor Environment
     - Criteria-Based Control
   - **Condition-Based Maintenance**
     - Timely Repair By Module Replacement
     - Indicates Performance Reserve To Operator
   - **Fault Tolerance**
     - Duality of All Critical Components
     - No Single Point Failures
     - Good Side Compensates For Weak Side
     - Continuous Operation Under A Fault
     - Limp Home at 50% Capacity
3. **ACTUATOR DESIGN CONCEPTS**
   - **Switched Reluctance Motor**
     - Low Speed/High Torque
     - High Efficiency/Low Heat Generation
   - **Rugged Gear Train Design**
     - Low Speed Generates Less Noise
     - Precision (Class 13 to 15) Gears Are Quieter
   - **Special Electronic Controllers**
     - Embedded Intelligence
     - Soft Response Commands
     - Generates Fewer High Harmonics
   - **Shell Design**
     - Rugged/Shock Resistant
     - Absorbs Electrical and Mechanical Signals

SUGGESTED WATER PLANE ACTUATORS

1. **BOW PLANE TILT ACTUATOR**
   - **Use Linear Spindle Screw Actuator**
     - Backfit Hydraulic Actuator
2. **BOW PLANE RETRACTING LINEAR ACTUATOR**
   - **Use Self-Contained Linear Actuator**
     - Backfits Hydraulic Actuator
3. **BOW PLANE DIRECT ROTARY DRIVES**
   - **Replaces Hydraulic Linear Tilt Actuator**
   - **Two Separate Rotary Drives**
     - On Both Sides of Centerline Bearing
     - Provide large Inner Diameter for Shaft
4. **SEPARATE BOW PLANE DIRECT ROTARY DRIVES**
   - **Remove All Tilt Mechanism Structure**
   - **Two Separate Rotary Drives**
     - Place Between Split Bearing Carrier Halves
     - Join With Clutched Drive Tube
     - Umbilical Through Retracting Actuator
5. **SPLIT STERN PLANE DRIVES**
   - **Use Linear Spindle Screw Actuator**
     - Backfit Large Hydraulic Cylinders
     - Preserve All Existing Actuation Structure
6. **MANEUVERING WATER PLANES**
   - **On New Propeller Shroud Housing**
     - 4, 6, or 8 Planes
     - Direct Rotary Drives In Shroud
   - **Potential For Low Dexterity Surfaces**
     - Inside Shroud
     - Improves Propulsion Efficiency
     - Reduces Noise
     - Improves Maneuverability
7. **TRIM TAB ACTUATOR**
   - **Small Trim Tab on Stern Planes**
     - Improves Ship Control
     - Two (or Three) Dual Actuators
     - Fit Within Present Stern Plane Geometry

SPLIT STERN PLANES





RETRACTABLE BOW PLANES
(EXTENDED POSITION)

HIGH TORQUE ROTARY ACTUATOR

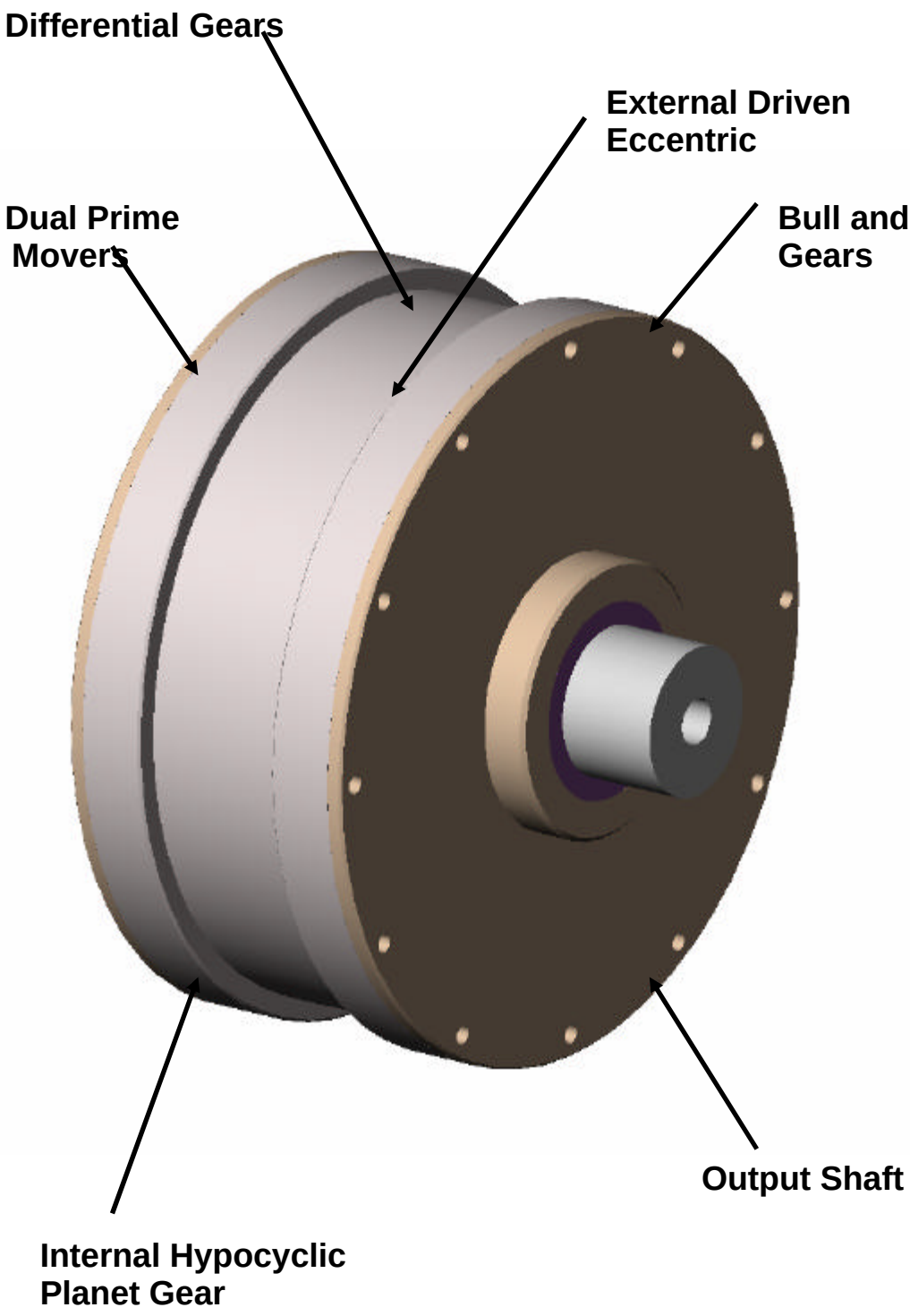
(750,000 ft.-lb. To Drive Submarine Water Vanes)

1. Step Towards All-Electric Ship

- **Replace Hydraulic Cylinders**
  - Old Legacy Technology
  - Noisy/Energy Intensive
  - Hull Seals Required
  - Complex Structural Layout (Linkages, Bearings, Shafts)
- **Self-Contained Drive Module**
  - Provides External Drive
  - Compact/Lightweight
  - Extremely Rugged
  - Water Vane Attaches Directly to Module
  - No Bearing and Shaft Required

2. Proposed Actuator Attributes

- **750,000 FT.-LB. torque Capacity**
  - Surge Demand Is Feasible
- **Width – 24”, Diameter – 45”**
  - Extraordinary Power Density
- **Mounted Outside Ship Hull**
  - Provides Water Vane Bearing Support
  - High Shock Resistant
- **Reduced Emissions**
  - Near Zero Emissions Is Possible
  - High Shock Resistant
  - Intelligence SFW Reduces Motor Noise
  - Exceptionally Quiet Gear Trains



CAD Drawing of High Torque Fault Tolerant Actuator

Fault Tolerant Water Vane Actuator

(Small Output Shaft, 90,000 ft.-lb. Capacity)

General Requirements

Range of Motion	**±35 degrees**
Speed	**1.67 RPM**
Temperature	**-30° to 60° F**
Pressure	**400 psi**

Static Loading (Margin over Recommendations)

Output Torque	**91,500 Ft.-lb.** (+2%)
Vertical Force	**137,000 lb.** (+120%)
Fore/Aft Force	**137,000 lb.** (+4%)
Axial Force	**23,000 lb.** (-18%)

Efficiency

Overall	**67%**
Friction Losses	**8.7%**
Gear Train Losses	**18%**
Prime Mover Losses	**6.3%**

Sizing (Recommended)

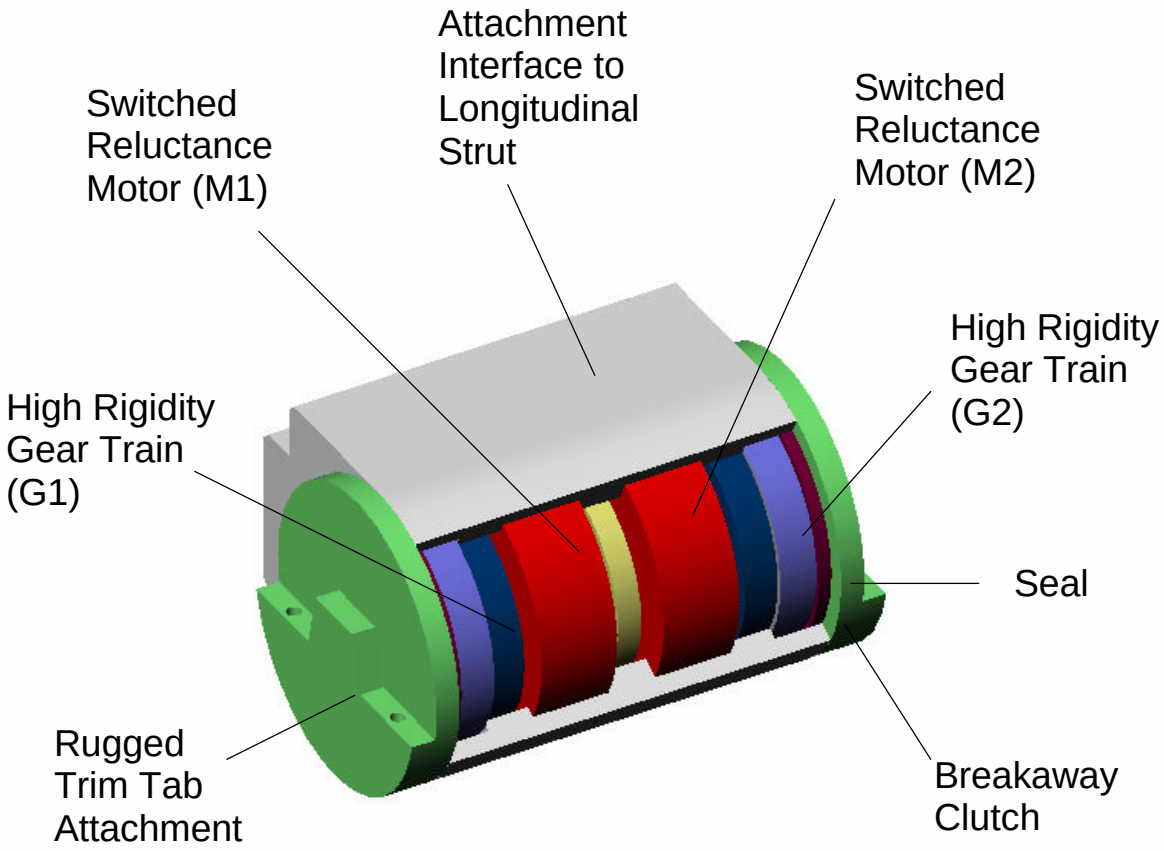
Output Shaft	**8”** (8”)
Width	**14”** (15”)
Diameter	**32”** (36”)
Est. Weight	**3650 lb.** (4330 lb.)

Gearing Issues

Reduction Ratio	**203 to 1**
Circular Arc Gear Teeth	**Desirable**
Expected Noise	**Low**
Wobble Plate Balancing	**Essential**
Friction Losses Study	**Desirable**

Comment: This Design Is Primarily A Torque Producer.

CONCEPT DESIGN FOR DUAL, HIGH STIFFNESS, LOW VOLUME, TRIM TAB ACTUATOR



Max. Speed [deg/sec]	**14**	Diameter [in]	**6.0**
Peak Cont. Torque [in-lb]	**100,000**	Length [in]	**15**
Max. Output Power [hp]	**3.7**	Weight [lb]	**120**

ACTUATOR EVALUATON FOR SUBMARINE TRIM TAB ASSISTED CONTROL

TRIM TAB FUNCTION

- **Attached To Trailing Edges of Existing Control Plane Surfaces**
- **Finer Depth Control, Maneuvering**
- **Lift Enhancement/Reduction**
- **Primary Actuator Torque Reduction**

ACTUATOR REQUIREMENTS

- **Load Capacity** (300,000 in-lb.) (# Actuators per Tab)
- **Compactness** (,800 in^3)
- **Temperature** (-35 to 150^o F)
- **Motion Range** (± 30^o)
- **Complex Duty Cycle**
- **Shock/Vibration** (MilStd)
- **Accuracy** (0.5^o)
- **Actuator Speed** (0.25 rad./sec.)
- **Lock In Place**
- **Reliability** (>10yr)
- **Maintainability**
- **EMI** (MilStd)
- **Fault Tolerance**
- **Weight**
- **Cost**
- **Tech Maturity**
- **Simplicity**
- **Diagnostics**
- **Environmental**

Open Architecture Issues

1. **SMART SHIP PROGRAM** (NRAC STUDIES)
   - **Ship To Warfighter Logistics** (1997)
   - **CVX Flexibility (1997)**
   - **Information Technology Throughout Ship**
   - **Reduce Ship Manning by 50%**
   - **Open Up Mechanical Architecture of Ship**
     - Modular, Upgradable, Maintainability
     - Reduce Total Ownership Cost
     - Build Ship of Standardized Active Components
     - Higher Performance/Reduced Costs
     - Plug-and-Play by Ship Personnel
     - Reduced Set of Logistics Spares
2. **POWER ELECTRONIC BUILDING BLOCKS** (PEBBs)
   - **Openness of Ship Electronics**
   - **Continuous Upgrades**
   - **Reduces Deployment Cost**
   - **Repair By Rapid Module Replacement**
3. **STANDARDIZED ACTUATOR BUILDING BLOCKS** (SABBs)
   - **Openness of Mechanical Architecture of Ship**
     - Minimal Set of Standard Actuator Modules
     - Drive Valves, Doors, Hatches, Etc. Throughout Ship
     - Build On Demand, Open Architecture Robots
   - **Robots For Human Intensive Tasks**
     - Scullery, Stores Handling, Warehousing
     - Bilge Cleaning, Hull Inspection and Cleaning
     - Aircraft Re-Manufacturing
4. **WEAPONS HANDLING**
   - **Now Requires 400(+) Personnel**
     - Forklifts, Weapons Carts
   - **Manpower Reduction Requires Automation**
     - Loading Platform To Aircraft Loading
     - 10 Handling Steps
     - Reduce Manpower to 100(+)
   - **30-Year Benefits**
     - $250,000,000 Cost Savings
     - Reduces Logistics Trail
     - Improves Survivability
     - Reduces Threat of Obsolescence

Weapon's Handling Systems

NINE HANDLING STEPS

- **Mobile Transport Platform**
  - Low Profile (12" high)
  - High Dexterity
  - Eight Identical Actuators
- **Weapons Containerization**
  - Standardized Handling Trays
  - Use Hard Points On Trays
  - Excess Fiduciary Marks
- **Heavy Duty Lifting Manipulators**
  - Lifts Up to 6,000 lbs
- **Precision Dexterous Assembly Manipulators**
  - Accuracy to 0.01 inch
  - Operates In Heavy Seas
  - Specialized Assembly End-Effector Tools
- **Warehousing Systems**
  - 3 DOF Handling Cranes
  - 3 DOF Alley Transporters
- **Medium Build-Up Assembly Cell** (500 lb.)
- **Large Build-Up Assembly Cell** (2000 lb.)
- **Containers For All-Up Rounds**
- **Hangar Aircraft Loading System**
- **Deck Aircraft Loading System**

How Can This Be Done?

1. OPEN ARCHITECTURE COMPUTER CONTROLLERS

- **Performance Increasing**
- **Cost Coming Down**
- **Gigaflop Exists Today**
  - Generalized Operating System
  - Cost of Approximately $10,000

2. COVERS ALL ACTIVE SHIP OPERATIONS

- **Driven By Minimal Set of SABBs**
- **Cost From $2,000 to $12,000**
  - Shock Resistance May Raise Cost
  - Thirteen Distinct Modules Suggested
  - Self Contained Systems
  - Wiring, Motors, Brakes, Sensors, Etc.

3. PLUG-AND-PLAY FOR SABBs

- **Standardized Interfaces**
- **Rapidly Replaced**
  - By Nominally Trained Operator
  - Highly Trained Personnel Unnecessary
- **Minimal Logistics Spares**

4. DIFFUSION OF TECHNOLOGY

- **Rapid Insertion of New Component Technology**
  - Brakes, Sensors, Motors, Etc.
  - Does Not Disturb External Standards
  - Reduced Risk To Decision Maker
  - Encourages Rapid Technical Development
  - Continuous Cost Reduction
  - Continuous Performance Enhancement

5. UNIVERSAL OPERATING SOFTWARE

- **Assemble Systems On Demand**
  - From 1 DOF Up To 20 DOF
- **Open Architecture Software Structure**
  - Upgradable and Downgradable
- **Modern Systems Management**
  - Maximum Performance Envelope
  - Condition-Based Maintenance
  - Fault Tolerance